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CO-OCCURRENCES OF SARDINE AND ANCHOVY LARVAE IN THE CALIFORNIA CURRENT REGION OFF CALIFORNIA AND BAJA CALIFORNIA

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This is a report on the co-occurrences of sardine and anchovy eggs and larvae in the collections of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) during 1951–60. More important, it is also a study of the interaction between two species of fish—both filter-feeders on planktonic organisms—occupying the same trophic level. This study leads further into the problem of whether there is a limit to the biomass of sardines plus anchovies that can be accommodated in the environment and whether one species increases in abundance only at the expense of the other.

During the period of the CalCOFI surveys, which began in 1949, the population of the Pacific sardine (*Sardinops caerulea*) as determined from the distribution and abundance of eggs and larvae, decreased markedly, especially since 1954. In contrast, the population of the northern anchovy (*Engraulis mordax*), as determined from the distribution and abundance of larvae, increased spectacularly. This relation brings up the question of whether the anchovy is moving into the ecological niche previously occupied by the sardine.

CalCOFI survey cruises have been made off California and Baja California for more than 15 years. Coverage was fairly intensive in 1949–60, when cruises were made at approximately monthly intervals. In 1961–64, cruises were spaced at quarterly intervals. Temporal coverage, consequently, was much better during the decade 1951–60, the years dealt with particularly in this report.

One of the difficulties in working up the observations on sardine and anchovy eggs and larvae is the massiveness of the data. Even the data for the 10-year period, 1951–60, are based on more than 16,000 separate collections. Anchovy larvae occurred in 6,755 collections, or 42.1 percent of the total, and sardine larvae in 2,133, or 14.3 percent. These data can be examined in many different ways. For example, the sardine and anchovy larvae from all collections are measured by 1-millimeter intervals, for abundance and survival studies. Was survival of larvae better in samples where anchovy and sardine larvae co-occurred, or in samples where the larvae of one species occurred alone? What was the relation of co-occurrences to the temporal and areal distributions of the larvae of the two species or to their relative abundances per haul? What was the influence of changing environmental conditions on the frequency with which sardines and anchovies co-occurred?

The CalCOFI survey cruises initially were planned to delimit and assay the distribution and abundance of the planktonic eggs and larvae of the Pacific sardine to determine indirectly the distribution and abundance of the adult population at time of spawning and to obtain information on the factors affecting the survival of year classes. Sardine spawning was found to have an extensive and variable areal distribution and to take place during much of the year, especially off Baja California. Consequently, we tried to cover systematically a rather large area of the ocean off California and Baja California.

The CalCOFI station pattern is illustrated in Figure 1. Inasmuch as I plan to discuss the distribution and abundance of eggs and larvae in different parts of the CalCOFI region, I have subdivided it into 7 areas—three off California and four off Baja California. The station lines included in each area are as follows:

Area	*Station Line*
Northern California	40– 57
Central California	60– 77
Southern California	80– 93
Northern Baja California	97–107
Upper central Baja California	110–120
Lower central Baja California	123–137
Southern Baja California	140–157

Not all areas were covered on each cruise. Four were consistently worked—those lying between station lines 80–137. The majority of cruises also included the central California area. Usually only 1 or 2 cruises per year were made off northern California and southern Baja California. With rare exceptions, only a single plankton haul was taken at each station occupied during a cruise.

In the course of obtaining information about sardine eggs and larvae, we also obtained information about many other fishes with planktonic young. Even at the beginning of the surveys, sardine larvae were outnumbered by larvae of northern anchovy (*Engraulis mordax*), hake (*Merluccius productus*), rockfish (*Sebastodes* spp.), and usually jack mackerel (*Trachurus symmetricus*).

The occurrence of numerous species of larvae led to a decision to identify and enumerate all the kinds in the collections. This decision posed problems in identification, but these were solved with perseverance. It became evident that surveys of eggs and larvae constituted one of the indispensable methods of resource evaluation. Most pelagic fishes have planktonic stages that can be sampled more simply and quantitatively than the adults.

Larvae of the Pacific sardine and northern anchovy occur mainly off southern California and off most of Baja California. The sardine also occurs throughout the Gulf of California. The northern anchovy, a somewhat more temperate species, does not occur in the Gulf, and its larvae seldom occur south of Magdalena Bay. It ranges farther north, however, than the sardine. In recent years there has been little spawning off central California (north of Pt. Conception) by either anchovies or sardines, although

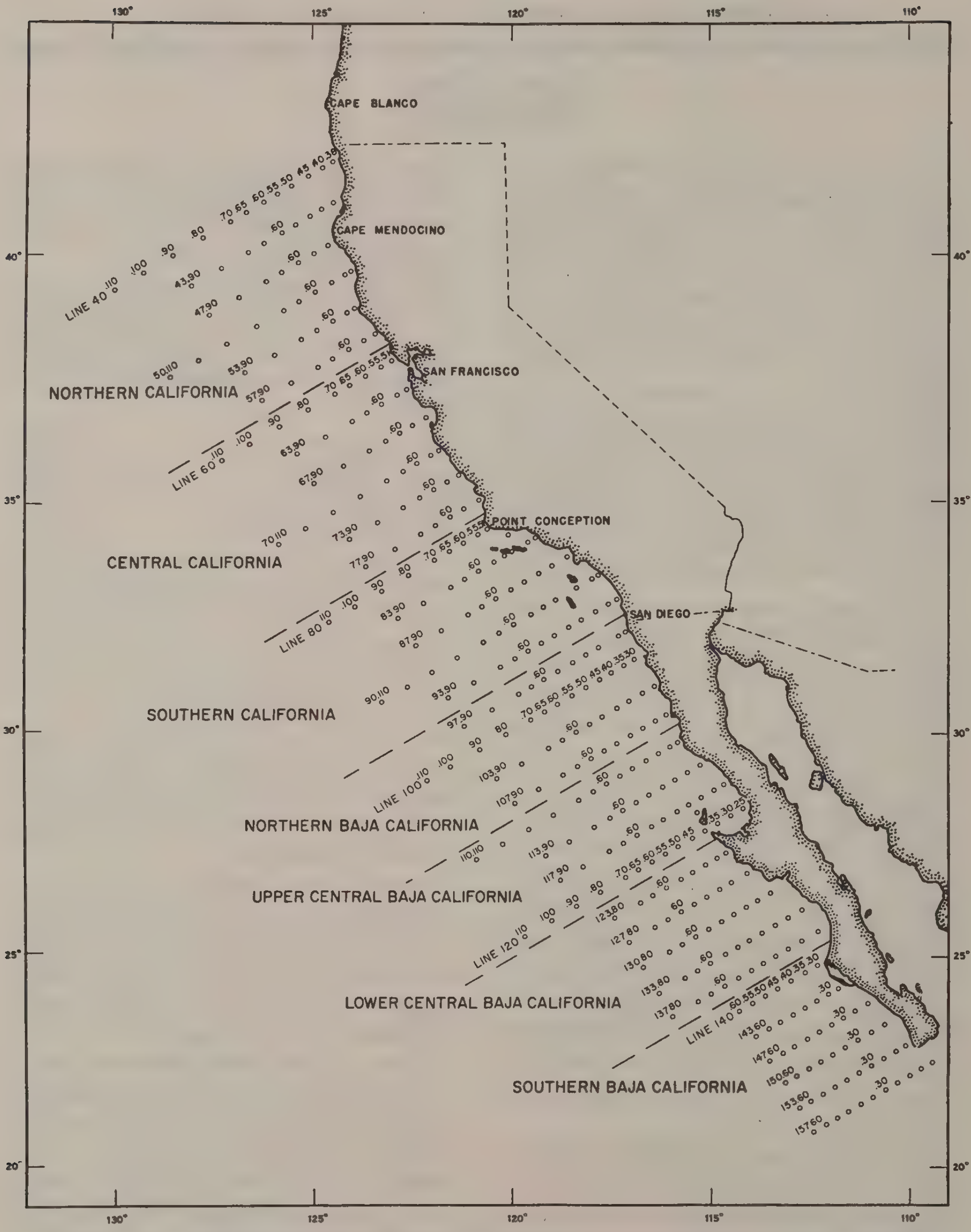
130°
125°
120°
115°
110°
40°
35°
30°
25°
20°
CAPE BLANCO
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
LINE 40
LINE 60
LINE 80
LINE 100
LINE 120
LINE 140
NORTHERN CALIFORNIA
CENTRAL CALIFORNIA
SOUTHERN CALIFORNIA
NORTHERN BAJA CALIFORNIA
UPPER CENTRAL BAJA CALIFORNIA
LOWER CENTRAL BAJA CALIFORNIA
SOUTHERN BAJA CALIFORNIA

FIGURE 1. Basic CalCOFI station grid off California and Baja California (station lines 40–157); divisions into areas are indicated.

anchovy spawning was common during 1958 and 1959. Some anchovies spawn as far north as British Columbia.

A most important consideration of the data of 1951–60 is that we could define no such thing as an ''average'' distribution or abundance of either species. Each year differed from every other year. The distributions of both species changed from year to year; the changes reflected their response to the varying oceanic environment. The changes in abundance of the two species, however, were more systematic, as is noted later.

Examples of changing distributions are pointed out here. One of the most marked changes in the distribution of sardine eggs and larvae occurred in the 1953 and 1954 season. In 1953, nearly all sardine spawning was off central Baja California; only about 1 percent was to the north. In 1954, spawning spread distinctly northward, and was widespread off both northern Baja California and southern California. The spawning in these ''northern'' areas increased to more than 38 percent of the season's total.

Variations in the spawning may be temporal as well as areal. A marked temporal change in sardine spawning occurred off southern California in 1958. During the preceding years which were characterized by below-average temperatures in winter and early spring off southern California, most spawning was in May and June. In 1958, after temperatures had been above average in the eastern North Pacific since mid-1957, the peak of sardine spawning was in January 1958, and spawning extended over a 7-month period, from January to July.

Changes in the distribution of anchovy eggs and larvae were less spectacular, but nonetheless real. In 1956, one of the colder years in the California Current region during the 1950's, anchovy larvae were much more numerous off southern Baja California (lines 140 and south) than in previous years. In most years less than 1 percent of the anchovy eggs and larvae collected were from this area, but in 1956 the area contributed nearly 20 percent of the season's total. This change, in effect, indicated a southward extension of anchovy spawning of some 40 to 80 miles. In contrast, anchovy spawning spread northward in 1958 and 1959. During the 7 years before 1958, less than 1 percent of anchovy larvae were from CalCOFI stations off central California (north of Pt. Conception); the larvae were collected at only 58 of 803 stations occupied. The number of occurrences of anchovy larvae off central California rose to 101 in 1958 and 133 in 1959. In 1959 anchovy larvae occurred at more than half of the stations occupied off central California and constituted more than 10 percent of the total larvae from all areas. With the return of normal temperatures in 1960, the number of occurrences of anchovy larvae off central California dropped to 48.

Two markedly contrasting years, 1954 and 1962, illustrate changes in the areal distributions of the two species that also reflect changes in abundance. The areal distribution and relative abundance of sardine and anchovy larvae in 1954 are shown in Figure 2. During this year, sardine larvae were even more widely distributed than anchovy larvae. Note particularly that even in the offshore waters of southern California, sardine larvae were more abundant and more widely distributed than anchovy larvae. This distribution of sardine larvae (and eggs) was the most extensive ever encountered during CalCOFI surveys.

The distributions of anchovy and sardine larvae during 1962 are shown in Figure 3. Anchovies were widely distributed; they were collected at nearly one-half of the stations (454 of the 919 occupied). Sardine larvae occurred at 58 stations, or in only slightly more than 6 percent of the stations occupied during the year. Most occurrences of sardine larvae (38 of the 58) were in the summer and fall cruises, mostly from off central Baja California. Anchovy larvae outnumbered sardine larvae in 1962 collections by more than 90 to 1.

The two species have somewhat different seasonal distributions. This difference is illustrated in Figure 4, which shows for each species the percentage of the yearly total that was taken in each month during 1952–59. The peaks of abundance of the two species and the yearly patterns of abundance show little correspondence. Anchovy larvae tended to be markedly less abundant during the last half of each year, whereas sardine larvae usually had a second peak of abundance in August-September. This late-season abundance was confined to Sebastian Viscaino Bay and adjacent waters off central Baja California, and represents the spawning of the southern subpopulation.

Anchovy larvae outnumbered sardine larvae in the California Current region even at the time of high abundance of the sardine, as was the situation during spawning surveys off southern California in 1940 and 1941. The ratio of larval anchovies to sardines was 1.18: 1 in 1940 and 1.66: 1 in 1941. These values are ratios of numbers of larvae, not the biomass of the two respective populations. An adult anchovy weighs only about one-fifth as much as an adult sardine and has a shorter life span. John MacGregor (personal communication) has estimated that an anchovy produces about twice as many eggs per unit of weight as does a sardine. If survival is even roughly similar during the egg and larval stages of sardines and anchovies, then larvae can be converted to adult biomass by equating one sardine larva to two anchovy larvae.

Stations are not equally spaced in the CalCOFI survey pattern, but tended to be more closely spaced nearshore than offshore on all cruises and to be spaced closer throughout the survey area during the peak periods of spawning. It is necessary therefore to adjust for such unequal spacing when deriving estimates of abundance. This adjustment is accomplished by integrating collection data over area. Such a treatment of data on abundance yields what we term a ''census estimate.'' The estimates are derived for individual cruises, and each yearly estimate is simply the summation of monthly cruise estimates. Tables

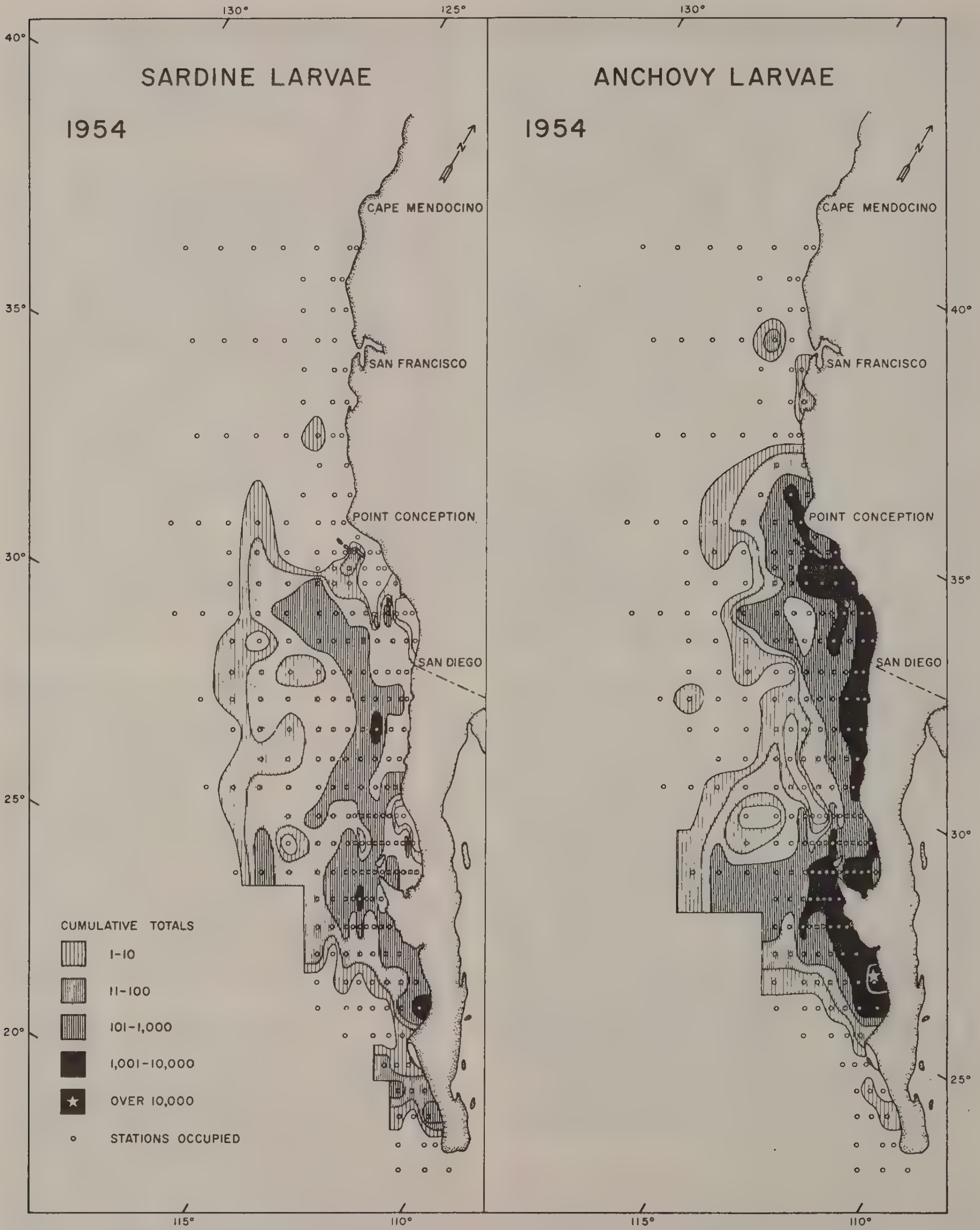
SARDINE LARVAE
1954
ANCHOVY LARVAE
1954
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
N
130°
125°
40°
35°
30°
25°
20°
115°
110°
CUMULATIVE TOTALS
1-10
11-100
101-1,000
1,001-10,000
OVER 10,000
STATIONS OCCUPIED

FIGURE 2. Distribution and relative abundance of sardine and anchovy larvae in the CalCOFI survey area in 1954.

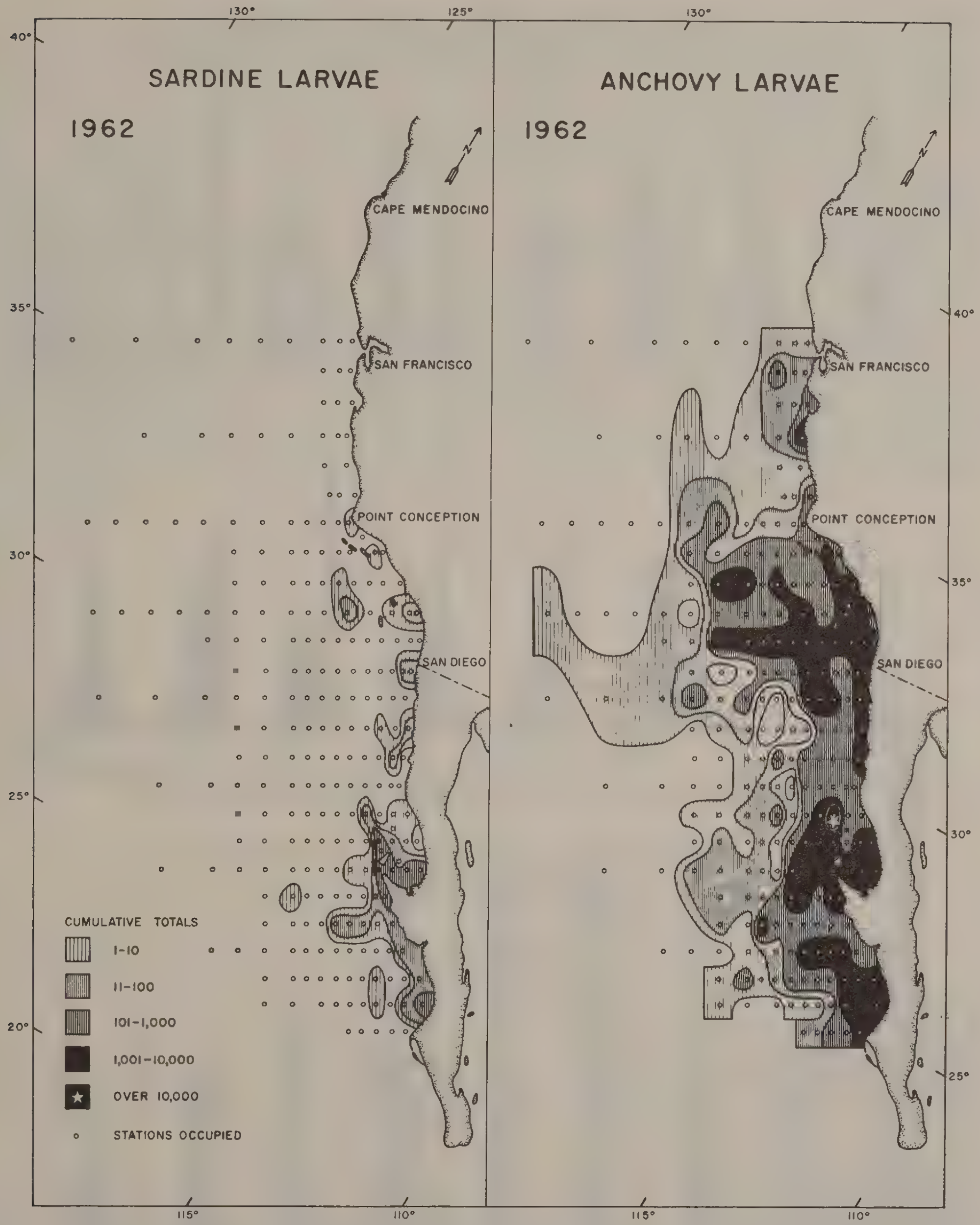
SARDINE LARVAE
1962
ANCHOVY LARVAE
1962
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
N
130°
125°
115°
110°
40°
35°
30°
25°
20°
CUMULATIVE TOTALS
1-10
11-100
101-1,000
1,001-10,000
OVER 10,000
STATIONS OCCUPIED

FIGURE 3. Distribution and relative abundance of sardine and anchovy larvae in the CalCOFI survey area in 1962.

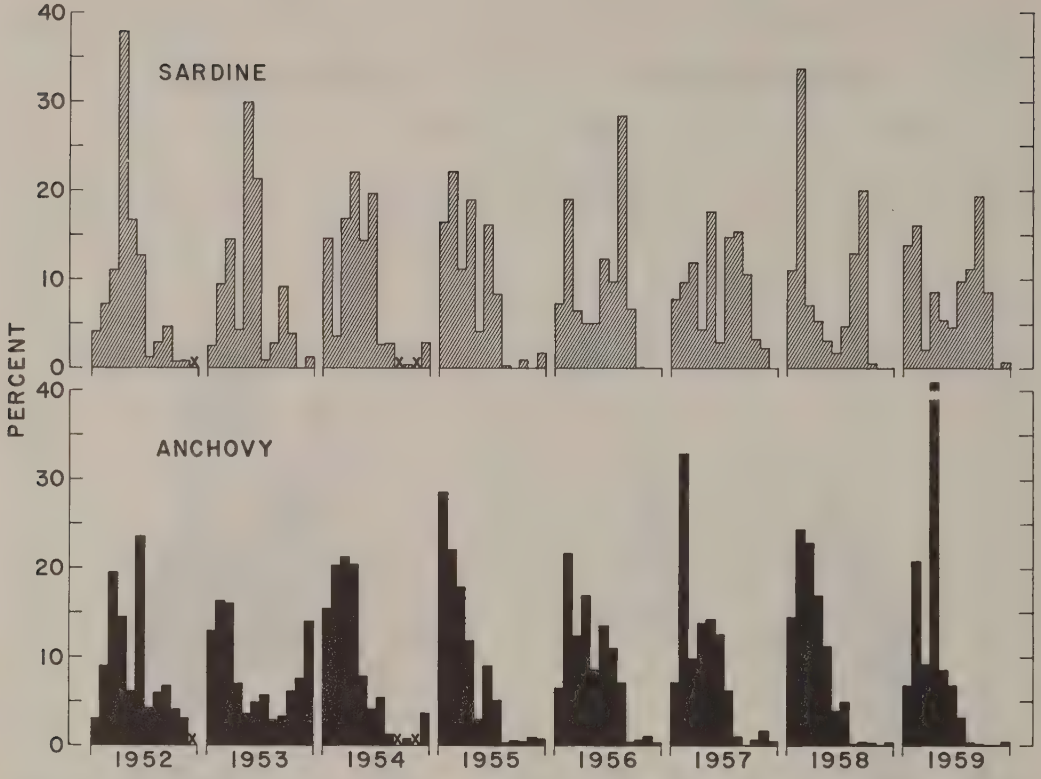

FIGURE 4. Percentages of the yearly total of sardine larvae (upper panel) and anchovy larvae (lower panel) taken in each monthly cruise, 1952–59. Spaces for each year on the abscissa depict a total of 12 months. X indicates no cruise was made.

TABLE 1

CENSUS ESTIMATES OF ABUNDANCE OF SARDINE LARVAE, BY YEAR AND AREA, 1951–59

(Estimates in Billions)

Area and station lines	Year								
	1951	1952	1953	1954	1955	1956	1957	1958	1959
Estimated number of larvae									
Northern California (40–57)	0	0	0	0	0	0	0	0	0
Central California (60–77)	3	0	0	2	0	0	47	7	7
Southern California (80–93)	146	189	2	1,691	528	433	569	491	427
Northern Baja California (97–107)	391	95	29	1,379	997	379	176	137	89
Upper central Baja California (110–120)	1,857	1,792	2,539	1,410	1,970	1,848	1,070	1,486	306
Lower central Baja California (123–137)	3,317	3,234	1,363	2,136	368	846	402	531	286
Southern Baja California (140–157)	60	156	87	679	478	389	168	179	44
Total	5,774	5,466	4,020	7,297	4,341	3,895	2,432	2,831	1,159
Percentage of yearly totals taken in each area									
Northern California (40–57)	0	0	0	0	0	0	0	0	0
Central California (60–77)	0.05	0	0	0.03	0	0	1.93	0.25	0.60
Southern California (80–93)	2.53	3.45	0.05	23.17	12.16	11.12	23.40	17.34	36.84
Northern Baja California (97–107)	6.77	1.74	0.72	18.90	22.97	9.73	7.24	4.84	7.68
Upper central Baja California (110–120)	32.16	32.78	63.16	19.32	45.38	47.44	44.00	52.49	26.40
Lower central Baja California (123–137)	57.45	59.17	33.91	29.27	8.48	21.72	16.53	18.76	24.68
Southern Baja California (140–157)	1.04	2.85	2.16	9.31	11.01	9.99	6.91	6.32	3.80
Total	100.00	99.99	100.00	100.00	100.00	100.00	100.01	100.00	100.00

TABLE 2

CENSUS ESTIMATES OF ABUNDANCE OF ANCHOVY LARVAE, BY YEAR AND AREA, 1951–59
(Estimates in Billions)

Area and station lines	Year								
	1951	1952	1953	1954	1955	1956	1957	1958	1959
Estimated number of larvae									
Northern California (40–57)	12	9	--	0	--	0	--	30	0
Central California (60–77)	371	140	2	962	20	205	71	3,196	5,750
Southern California (80–93)	2,112	1,769	5,203	10,295	7,450	4,673	21,010	21,853	25,529
Northern Baja California (97–107)	825	1,279	2,460	4,536	8,425	1,944	3,261	7,415	3,633
Upper central Baja California (110–120)	4,015	6,972	10,755	7,122	17,914	15,395	7,628	12,733	13,167
Lower central Baja California (123–137)	7,671	6,867	5,260	15,491	3,828	8,858	8,437	11,439	6,055
Southern Baja California (140–157)	95	35	--	9	21	7,433	34	262	34
Total	15,101	17,071	23,680	38,415	37,658	38,508	40,441	56,928	54,168
Percentage of yearly totals taken in each area									
Northern California (40–57)	0.08	0.05	--	0	--	0	--	0.05	0
Central California (60–77)	2.46	0.82	>.01	2.50	0.05	0.53	0.18	5.62	10.61
Southern California (80–93)	13.98	10.36	21.97	26.80	19.78	12.14	51.95	38.39	47.13
Northern Baja California (97–107)	5.46	7.49	10.39	11.81	22.37	5.05	8.06	13.02	6.71
Upper central Baja California (110–120)	26.59	40.84	45.42	18.54	47.57	39.98	18.86	22.37	24.31
Lower central Baja California (123–137)	50.80	40.23	22.21	40.33	10.17	23.00	20.86	20.09	11.18
Southern Baja California (140–157)	0.63	0.20	--	0.02	0.06	19.30	0.09	0.46	0.06
Total	100.00	99.99	100.00	100.00	100.00	100.00	100.00	100.00	100.00

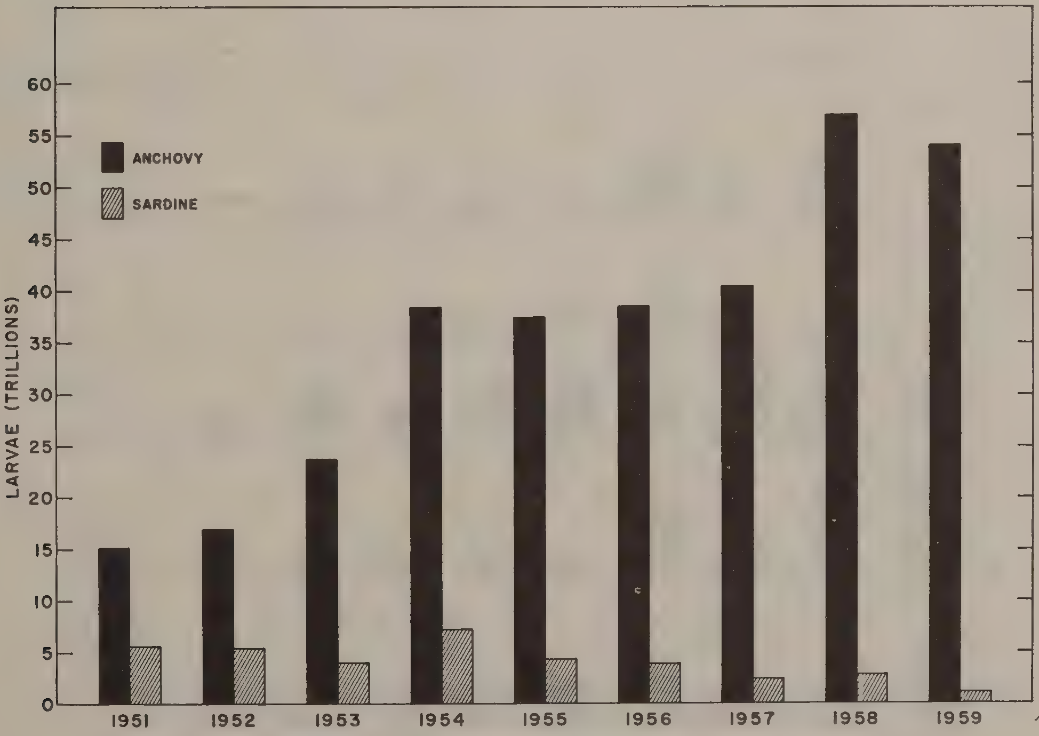

FIGURE 5. Annual census estimates for the total CalCOFI survey area of sardine and anchovy larvae, 1951–59.

1 and 2 show census estimates for sardine and anchovy larvae, respectively, for 1951–59, summarized by year and area. Census estimates for 1960 are not included, simply because they have not been worked up as yet. The estimates of sardine larvae ranged from a high of about 7.3 trillion in 1954 to a low of about 1.2 trillion in 1959. Anchovy larvae increased from 15.1 trillion to more than 38 trillion between 1951 and 1954, remained at this level through 1957, and then increased further to about 55 trillion in 1958 and 1959 (Figure 5). Anchovy abundance appears to have almost quadrupled during the 1950's, while sardine abundance progressively decreased after 1954. Whereas anchovy larvae outnumbered sardine larvae by less than 3:1 in 1951, the ratio had increased to more than 45: 1 by 1959. Abundance of anchovy larvae increased further from 1960 to 1965. Although this change is not shown or expressed in

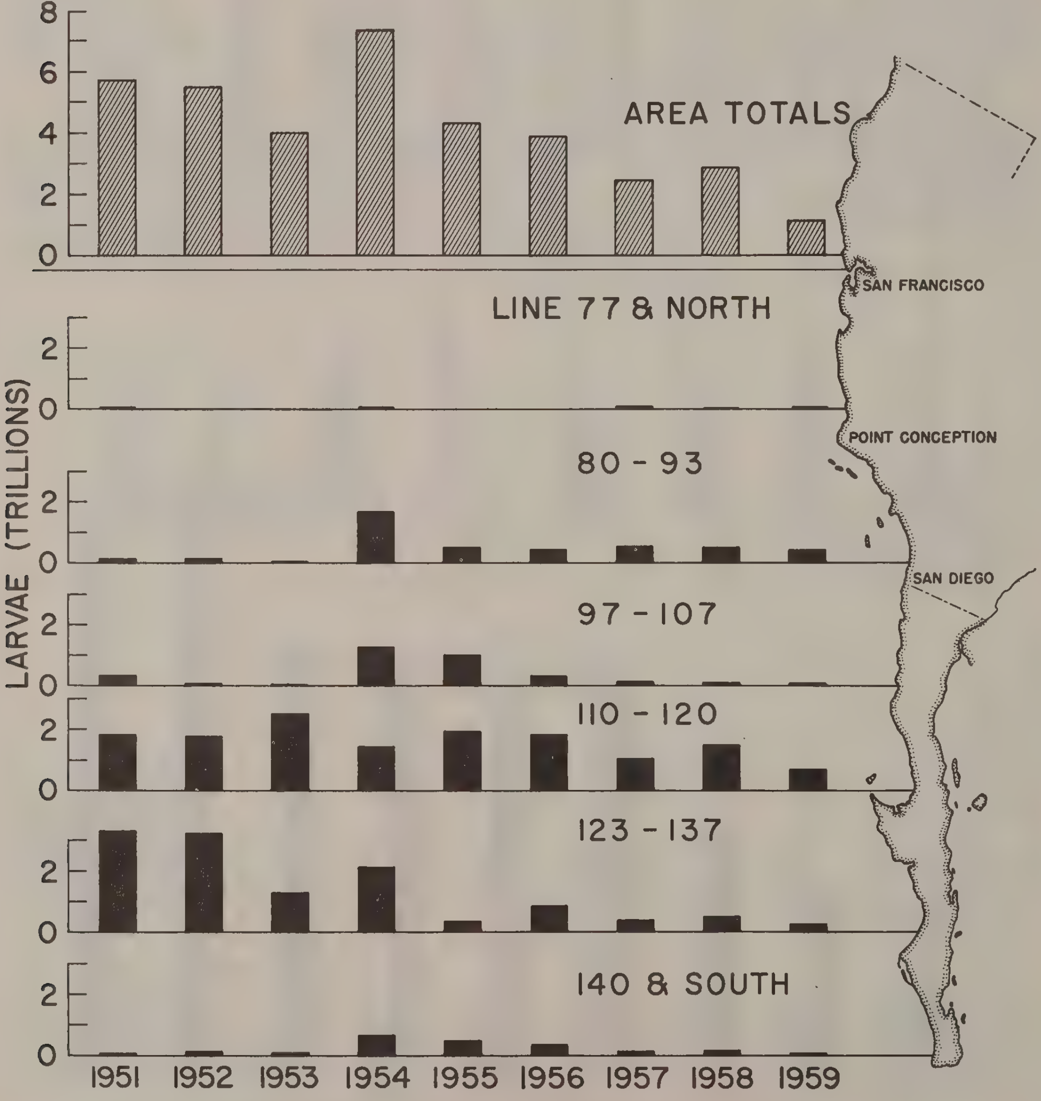

FIGURE 6. Sardine larvae: Annual census estimates [illegible]a, 1951–59.

terms of census estimates (only four cruises were made per year after 1960, rather than 10 to 12), other methods of evaluating the increase indicate that abundance more than doubled between 1958 and 1965.

The census estimates permit a better evaluation of abundance of sardine and anchovy larvae in the 7 areas of the CalCOFI region during 1951–59.

As already noted, sardine eggs and larvae were obtained more consistently off central Baja California (lines 110-137) than off northern Baja California and southern California (Figure 6). Sardine larvae were proportionately more abundant, however, off lower central Baja California (station lines 123–137) during 1951–54 than later. Off northern Baja California (lines 97–107) and southern California (lines 80–93) abundance was low in 1951–53 but proportionately higher during 1954–59.

Throughout the decade only negligible numbers of sardine larvae were taken off central California (lines 60–77) and none off northern California. The numbers taken off southern Baja California (lines 140–157) undoubtedly would have been higher if this area had

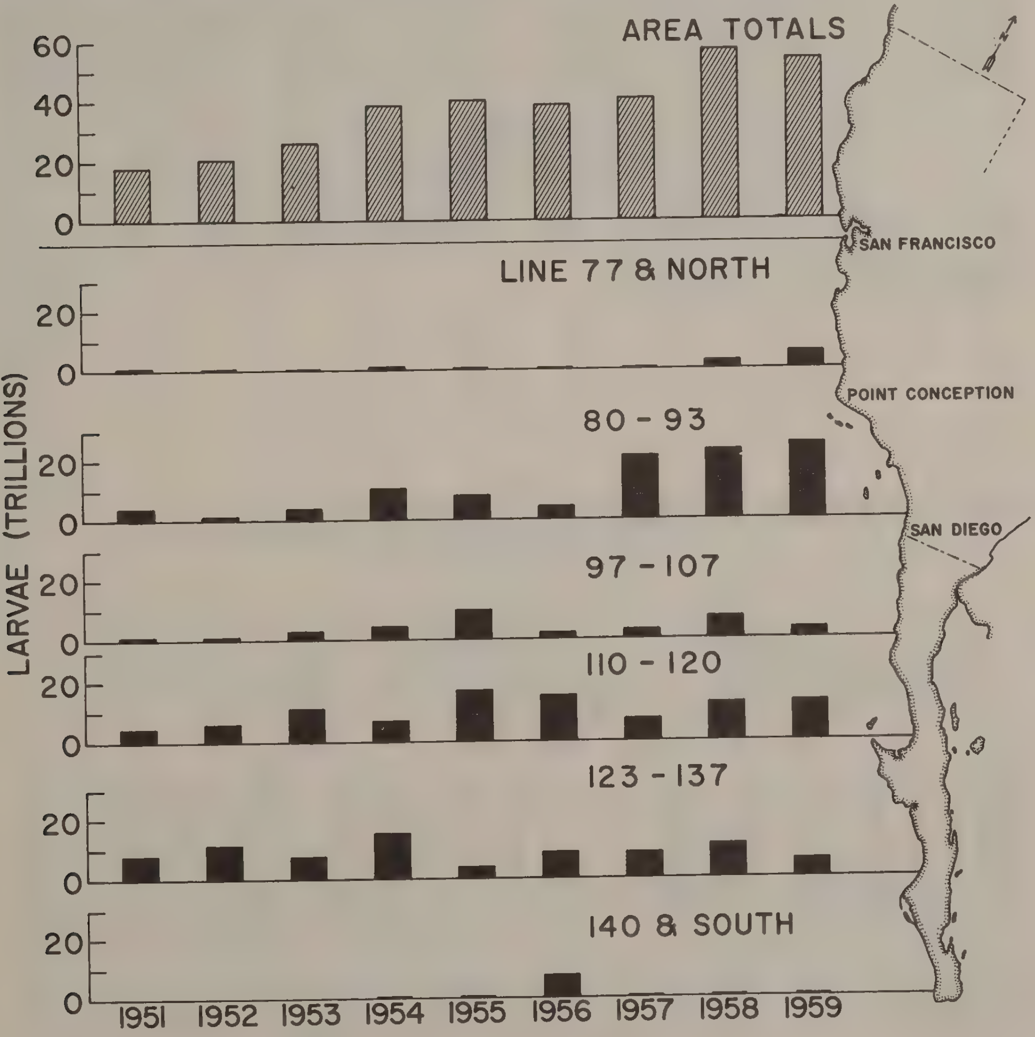

FIGURE 7. Anchovy larvae: Annual census estimates by area, 1951–59.

TABLE 3

SARDINE LARVAE[1]: SUMMARY OF TOTAL OCCURRENCES, CO-OCCURRENCES WITH ANCHOVY LARVAE, AND OCCURRENCES IN HAULS WITHOUT ANCHOVY LARVAE IN THE CalCOFI SURVEY PATTERN, BY AREA AND YEAR, 1951–63

(Station lines given below each area [2])

Year	Total occurrences of sardine larvae							Co-occurrences of sardine and anchovy larvae							Occurrences of sardine larvae alone						
	Cent. Calif. 60–77	So. Calif. 80–93	No. Baja Calif. 97–107	Upper cent. Baja Calif. 110–120	Lower cent. Baja Calif. 123–137	So. Baja Calif. 140–157	Total	Cent. Calif. 60–77	So. Calif. 80–93	No. Baja Calif. 97–107	Upper cent. Baja Calif. 110–120	Lower cent. Baja Calif. 123–137	So. Baja Calif. 140–157	Total	Cent. Calif. 60–77	So. Calif. 80–93	No. Baja Calif. 97–107	Upper cent. Baja Calif. 110–120	Lower cent. Baja Calif. 123–137	So. Baja Calif. 140–157	Total
Monthly cruises																					
1951	1	23	26	55	55	9	169	0	10	12	47	46	3	118	1	13	14	8	9	6	51
1952	0	25	21	101	109	6	262	0	12	9	65	79	2	167	0	13	12	36	30	4	95
1953	0	3	8	110	91	7	219	0	3	2	72	74	0	151	0	0	6	38	17	7	68
1954	1	42	92	132	96	11	374	0	22	42	86	79	4	233	1	20	50	46	17	7	141
1955	0	26	72	94	47	17	256	0	12	34	79	32	3	160	0	14	38	15	15	14	96
1956	0	22	39	61	38	11	171	0	3	15	55	32	4	109	0	19	24	6	6	7	62
1957	6	21	22	83	31	12	175	2	9	16	60	20	3	110	4	12	6	23	11	9	65
1958	2	71	26	53	30	13	195	2	67	23	44	26	6	168	0	4	3	9	4	7	27
1959	5	68	16	53	25	5	172	5	66	15	43	20	3	152	0	2	1	10	5	2	20
1960	0	40	26	46	18	10	140	0	39	21	39	14	8	121	0	1	5	7	4	2	19
Total	15	341	348	788	540	101	2,133	9	243	189	590	422	36	1,489	6	98	159	198	118	65	644
Quarterly cruises																					
1961	0	16	6	16	13	1	52	0	12	6	16	10	1	45	0	4	0	0	3	0	7
1962	0	9	6	22	21	0	58	0	8	6	20	18	0	52	0	1	0	2	3	0	6
1963	3	19	25	28	20	1	[2]96	3	16	23	24	19	1	86	0	3	2	4	1	0	10

[1] No sardine larvae were obtained off northern California (station lines 40–57).

[2] Includes additional closely spaced stations on inshore ends of station lines.

TABLE 4

ANCHOVY LARVAE: SUMMARY OF TOTAL OCCURRENCES, CO-OCCURRENCES WITH SARDINE LARVAE, AND OCCURRENCES IN HAULS WITHOUT SARDINE LARVAE IN THE CalCOFI SURVEY PATTERN, BY AREA AND YEAR, 1951–63

(Station lines given below each area)

Year	Total occurrences of anchovy larvae								Co-occurrences of sardine and anchovy larvae								Occurrences of anchovy larvae alone							
	No. Calif. 40–57	Cent. Calif. 60–77	So. Calif. 80–93	No. Baja Calif. 97–107	Upper cent. Baja Calif. 110–120	Lower cent. Baja Calif. 123–137	So. Baja Calif. 140–157	Total	No. Calif. 40–57	Cent. Calif. 60–77	So. Calif. 80–93	No. Baja Calif. 97–107	Upper cent. Baja Calif. 110–120	Lower cent. Baja Calif. 123–137	So. Baja Calif. 140–157	Total	No. Calif. 40–57	Cent. Calif. 60–77	So. Calif. 80–93	No. Baja Calif. 97–107	Upper cent. Baja Calif. 110–120	Lower cent. Baja Calif. 123–137	So. Baja Calif. 140–157	Total
Monthly [redacted]																								
1951	6	43	89	59	107	95	11	410	0	0	10	12	47	46	3	118	6	43	79	47	60	49	8	292
1952	1	11	110	92	169	134	2	519	0	0	12	9	65	79	2	167	1	11	98	83	104	55	0	352
1953	--	2	228	91	199	165	0	685	--	0	3	2	72	74	0	151	--	2	225	89	127	91	0	534
1954	0	15	259	124	187	169	4	758	0	0	22	42	86	79	4	233	0	15	237	82	101	90	0	525
1955	0	7	218	120	178	94	7	624	0	0	12	34	79	32	3	160	0	7	206	86	99	62	4	464
1956	0	5	168	82	151	107	23	536	0	0	3	15	55	32	4	109	0	5	165	67	96	75	19	427
1957	--	17	187	94	172	98	12	580	--	2	9	16	60	20	3	110	--	15	178	78	112	78	9	470
1958	5	96	272	145	164	85	11	778	0	2	67	23	44	26	6	168	5	94	205	122	120	59	5	610
1959	0	133	311	116	197	120	11	888	0	5	66	15	43	20	3	152	0	128	245	101	154	100	8	736
1960	0	48	280	193	256	173	27	977	0	0	39	21	39	14	8	121	0	48	241	172	217	159	19	856
Total	12	377	2,122	1,116	1,780	1,240	108	6,755	0	9	243	189	590	422	36	1,489	12	368	1,879	927	1,190	818	72	5,266
Quarterly cruises																								
1961	--	30	115	84	102	69	1	401	--	0	12	6	16	10	1	45	--	30	103	78	86	59	0	356
1962	--	26	129	91	105	92	11	454	--	0	8	6	20	18	0	52	--	26	121	85	85	74	11	402
1963	--	40	171	97	133	97	4	542	--	3	16	23	24	19	1	86	--	37	155	74	109	78	3	456

been sampled as consistently as the others off Baja California.

The distribution of anchovy larvae was somewhat different than that of sardines (Figure 7). Anchovy larvae were important in the area off central California (lines 60–77) only during 1958 and 1959, and in the southernmost area (lines 140–157) only during 1956; they were taken in only a few hauls off northern California (lines 40–57). In the remaining areas, they were more consistently represented throughout the 10-year period than sardine larvae. Anchovy larvae, like sardine larvae, were more abundant off California during the warm years, 1957–59. In these years, the center of anchovy abundance shifted from central Baja California to southern California.

I wish now to deal more specifically with occurrences and co-occurrences of larvae and eggs of the two species. Information concerning occurrences and co-occurrences of the two species in the seven areas are summarized in Tables 3 and 4. For completeness, I have included information on occurrences and co-occurrences of both species for 1961–63, as well as for 1951–60. The total number of stations occupied on CalCOFI cruises during each year, 1951–63, are summarized by area in Table 5. These summations are not limited to regular CalCOFI stations, but include extra occupancies and special cruises (Table 6). However, the analysis that follows is based on the data for 1951–60.

Throughout the CalCOFI survey period, anchovy larvae always have occurred in more collections than sardine larvae (Figure 8). In the 1950's as a whole, anchovy larvae occurred in 3.1 times as many hauls as sardine larvae. The disparity was lowest in 1952

TABLE 5

SUMMARY OF STATIONS OCCUPIED ON CalCOFI SURVEY CRUISES, BY YEAR AND AREA, 1951–63

(Station lines given below each area)

Year	Northern California 40–57	Central California 60–77	Southern California 80–93	Northern Baja Calif. 97–107	Upper central Baja Calif. 110–120	Lower central Baja Calif. 123–137	Southern Baja Calif. 140–157	Total
Monthly cruises								
1951	45	243	337	258	263	201	89	1,436
1952	29	164	350	287	352	277	14	1,473
1953	0	119	478	249	319	267	13	1,445
1954	13	109	418	274	352	271	36	1,473
1955	7	95	403	302	353	212	79	1,451
1956	54	112	395	280	308	182	76	1,407
1957	0	101	364	287	360	267	114	1,493
1958	41	230	459	352	391	274	105	1,852
1959	22	232	572	419	473	345	119	2,182
1960	62	165	439	341	420	286	113	1,826
Total	273	1,570	4,215	3,049	3,591	2,582	758	16,038
Quarterly cruises								
1961	0	128	237	183	209	191	5	953
1962	0	85	243	185	210	182	15	920
1963	0	81	266	206	218	226	12	1,009

TABLE 6

STATIONS OCCUPIED ON REGULAR CalCOFI CRUISES AND SPECIAL CRUISES, INCLUDING EXTRA OCCUPANCIES, 1951–64

Year	Regular occupancies	Late March cruise	Extra occupancies of regular stations	Special tows	Additional inshore stations	Multiple occupancies (not included)	Total
Monthly cruises							
1951	1,436	0	0	0	0	0	1,436
1952	1,376	63	34	0	0	0	1,473
1953	1,346	63	36	0	0	0	1,445
1954	[1]1,473	0	0	0	0	0	1,473
1955	1,425	0	26	0	0	(166)	1,451
1956	1,399	0	8	0	0	0	1,407
1957	1,493	0	0	0	0	0	1,493
1958	1,851	0	1	0	0	(34)	1,852
1959	2,180	0	2	0	0	0	2,182
1960	1,810	0	1	15	0	(24)	1,826
Total	15,789	126	108	15	0	(224)	16,038
Quarterly cruises							
1961	944	0	9	0	0	0	953
1962	919	0	1	0	0	0	920
1963	881	0	3	0	125	0	1,009
1964	877	0	7	0	319	0	1,203

[1] Includes 54 stations occupied on Norpac.

and 1954, when they were collected only twice as often as sardine larvae, but increased yearly in 1955–60; in the 1960 collections, anchovy larvae occurred seven times as often as sardine larvae. A corresponding increase appeared in the co-occurrences of anchovy larvae in the collections containing sardine larvae, from 62 percent in 1954 to about 87 percent in 1960.

Obviously, as one species becomes more abundant and more widespread than another, it will occur alone more frequently, and thus be free from possible competition. When anchovy larvae are collected in seven times as many hauls as sardine larvae, as in 1960, the possible co-occurrences with sardine larvae would be only 14 percent. In fact, sardine larvae co-occurred with anchovy larvae in one haul out of eight (12.4 percent), while anchovy larvae co-occurred with sardine larvae in six hauls out of seven (86.5 percent).

For the decade as a whole, anchovy larvae co-occurred in 1,489 (69.8 percent) of the 2,133 hauls that contained sardine larvae, whereas sardine larvae occurred in only 1,489 (22.0 percent) of the 6,755 hauls that contained anchovy larvae. Thus, anchovy larvae were present in two of every three hauls that contained sardine larvae, whereas sardine larvae occurred in little more than one of five hauls containing anchovy larvae. If interspecies competition is a factor in the survival of larvae, and co-occurrence is a measure of competition, then the anchovy should have had a decided advantage over the sardine.

Another factor must be considered: sardine larvae are less likely to occur with anchovy larvae in some areas of the CalCOFI grid than in others (Tables 7 and 8). Anchovy larvae have had decidedly less com-

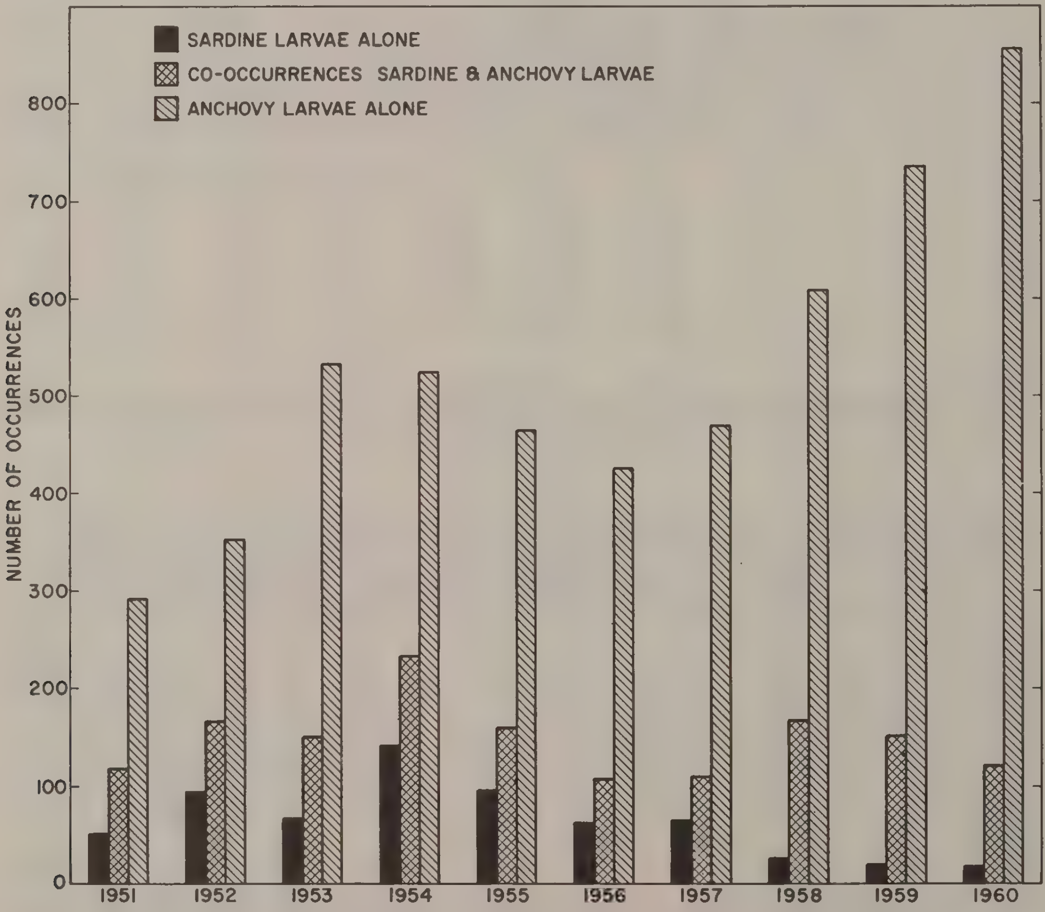

FIGURE 8. Graphic presentation, by year, of the number of CalCOFI plankton collections containing 1) sardine larvae alone, 2) both sardine and anchovy larvae, and 3) anchovy larvae alone, 1951–60

TABLE 7

SUMMARY OF TOTAL STATION OCCUPANCIES, OCCURRENCES OF SARDINE LARVAE, AND CO-OCCURRENCES WITH ANCHOVY LARVAE, BY AREA, 1951–60

Area and station lines	1951–60 total occupancies	Occurrences of sardine larvae	Percentage of positive hauls	Co-occurrences with anchovy larvae	Percentage of co-occurrences
Northern California (40–57)	273	0	0	0	0
Central California (60–77)	1,570	15	1.0	9	60.0
Southern California (80–93)	4,215	341	8.1	243	71.3
Northern Baja California (97–107)	3,049	348	11.4	189	54.3
Upper central Baja California (110–120)	3,591	788	21.9	590	74.9
Lower central Baja California (123–137)	2,582	540	20.9	422	78.1
Southern Baja California (140–157)	758	101	13.3	36	35.6
Totals	16,038	2,133	13.3	1,489	69.8

TABLE 8

SUMMARY OF TOTAL STATION OCCUPANCIES, OCCURRENCES OF ANCHOVY LARVAE, AND CO-OCCURRENCES WITH SARDINE LARVAE, BY AREA, 1951–60

Area and station lines	1951–60 total occupancies	Occurrences of anchovy larvae	Percentage of positive hauls	Co-occurrences with sardine larvae	Percentage of co-occurrences
Northern California (40–57)	273	12	4.4	0	0
Central California (60–77)	1,570	377	24.0	9	2.4
Southern California (80–93)	4,215	2,122	50.3	243	11.5
Northern Baja California (97–107)	3,049	1,116	36.6	189	16.9
Upper central Baja California (110–120)	3,591	1,780	49.6	590	33.1
Lower central Baja California (123–137)	2,582	1,240	48.0	422	34.0
Southern Baja California (140–157)	758	108	14.2	36	33.3
Totals	16,038	6,755	42.1	1,489	22.0

petition in the northern part of the CalCOFI survey area. Off central California (station lines 60–77) sardine larvae occurred in less than 1 percent of the collections, while anchovy larvae occurred in 24 percent. In this area the percentage of co-occurrence of sardine with anchovy larvae was only 2.4 percent. Off southern California, anchovy larvae occurred in more than 50 percent of all collections made during the 1950's, and sardine larvae in only 8.1 percent. Hence, even though the co-occurrence of anchovy larvae with sardine larvae was 71.3 percent, sardine larvae occurred in only 11.5 percent of the collections that contained anchovy larvae. Off southern California the anchovy must have had a decided advantage.

The region in which the two species might have competed most intensely was off central Baja California. In this region sardine larvae occurred in one of every three hauls containing anchovy larvae; anchovy larvae occurred in three of every four hauls containing sardine larvae.

The occurrences of eggs in our plankton hauls were less frequent than occurrences of larvae. Probably a major reason for this lower frequency is that eggs of both the Pacific sardine and the northern anchovy hatch in only 2 to 4 days, depending on water temperature; consequently the eggs in any given haul represent a relatively short time span. A sample of larvae, on the other hand, can contain specimens accumulated during a span of perhaps 30 days or more. Sardine eggs, on the average, occurred in only about 70 percent as many collections as sardine larvae. Anchovy eggs, which are not fully retained by the standard CalCOFI net, occurred in little more than a third as many hauls as anchovy larvae. Hence, the frequency of occurrence and, as it happens, co-occurrence of eggs is less than for larvae. In only 1958 and 1959 did sardine eggs co-occur in more hauls with anchovy eggs than they occurred alone. For the decade as a whole, anchovies spawned in the same waters with sardines only about 30 percent of

TABLE 9

COMPARISON OF AVERAGE NUMBER OF LARVAE PER HAUL OF "CO-OCCURRENCES," WITH SAMPLES CONTAINING SARDINE OR ANCHOVY LARVAE ALONE

	Sardine larvae			Anchovy larvae		
	All hauls	Alone	Co-occurring	Co-occurring	Alone	All hauls
1951	65.5	21.4	84.5	124.5	50.9	72.1
1952	93.8	82.5	99.9	192.2	88.2	121.8
1953	68.8	63.3	71.2	186.4	142.4	152.1
1954	72.0	47.9	86.5	304.0	172.3	212.7
1955	55.6	47.5	60.4	302.2	201.6	227.5
1956	90.7	57.2	109.9	329.0	232.0	251.8
1957	56.2	67.9	49.3	315.7	238.1	252.8
1958	58.9	27.0	64.0	610.4	169.5	264.0
1959	31.2	34.4	30.7	473.4	183.7	233.7
1960	60.6	17.8	67.3	494.9	271.5	299.1
Average	65.3	46.7	72.4	333.3	175.0	208.7

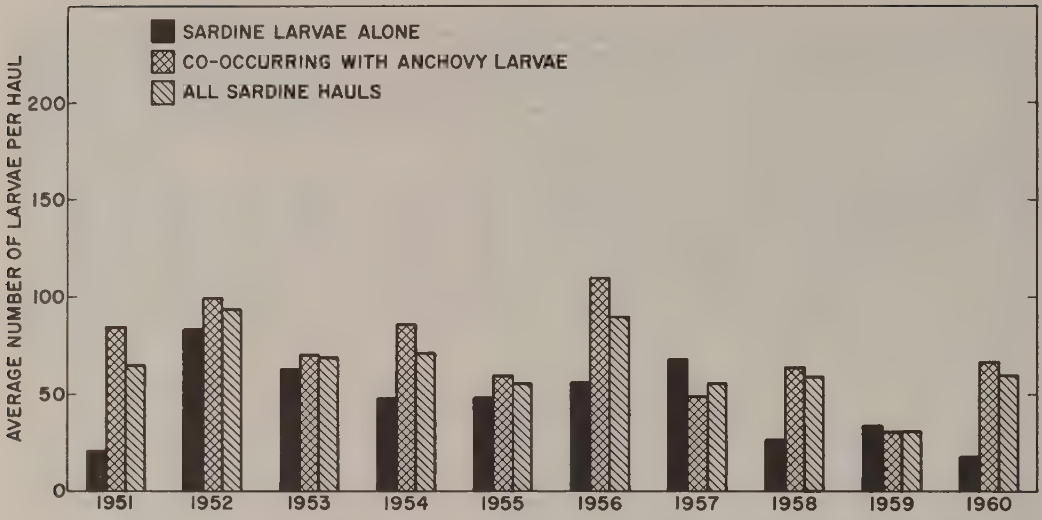

FIGURE 9. Comparison of the annual average number of sardine larvae obtained per haul, 1) in hauls containing sardine larvae alone, 2) in hauls in which sardine larvae co-occurred with anchovy larvae, and 3) in all hauls containing sardine larvae, 1951–60.

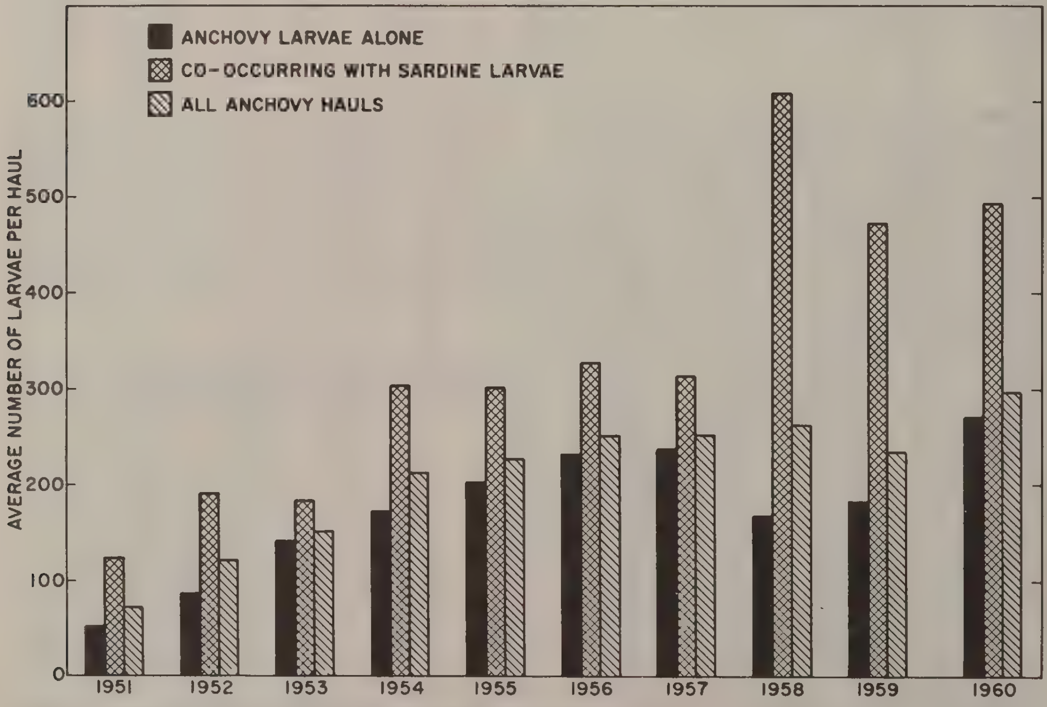

FIGURE 10. Comparison of the annual average number of anchovy larvae obtained per haul, 1) in hauls containing anchovy larvae alone, 2) in hauls in which anchovy larvae co-occurred with sardine larvae, and 3) in all hauls containing anchovy larvae, 1951–60.

the time. In contrast, the larvae of anchovies co-occurred with sardine larvae about 70 percent of the time.

The numbers of larvae in "co-occurring hauls" compared with hauls containing only one or the other species alone are summarized in Table 9 and illustrated in Figures 9 and 10. More larvae were obtained per sample in hauls where the two species co-occurred than in hauls where they occurred alone. The consistently larger numbers of anchovies taken in hauls containing sardine larvae over numbers in hauls containing anchovies alone, usually by about 2 to 1, was especially striking. Numbers of sardine larvae in samples that contained anchovy larvae usually were also considerably larger than in hauls where they occurred alone—only two exceptions in the 10-year series.

TABLE 10

SARDINE LARVAE—ALL OCCURRENCES: AVERAGE NUMBER PER POSITIVE HAUL (X 10²), SUMMARIZED BY SIZE AND YEAR, 1951–60

Size class (mm)	Year										Un-weighted average
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	
3.0	1,608	2,632	1,782	2,193	1,390	3,049	1,287	1,566	1,137	1,667	1,831.1
4.75	1,388	2,580	2,489	1,992	1,799	2,316	1,086	1,419	831	1,256	1,715.6
5.75	777	968	735	822	951	837	975	875	417	798	815.5
6.75	508	698	451	408	356	508	397	606	164	563	465.9
7.75	513	580	380	337	243	490	444	626	103	376	409.2
8.75	379	414	242	262	138	479	364	301	116	388	308.3
9.75	302	322	125	238	154	400	304	177	96	328	244.6
10.75	227	260	134	253	93	260	249	87	86	199	184.8
11.75	214	196	123	179	98	155	160	75	44	190	143.4
12.75	163	166	136	152	91	145	92	49	45	102	114.1
13.75	144	122	90	134	74	90	59	27	40	43	82.3
14.75	101	95	64	110	70	85	75	20	14	33	66.7
15.75	54	47	45	54	41	98	48	28	11	10	43.6
17.25	77.5	44.0	54.0	36.0	41.6	77.1	44.5	20.3	12.4	3.6	41.1
19.25	17.4	28.4	11.4	15.5	13.7	46.2	20.6	7.8	3.5	--	16.4
21.25	25.4	13.6	4.7	3.0	3.8	32.5	6.0	1.9	1.6	1.8	9.4
23.25	18.2	9.8	2.4	5.0	--	6.7	1.9	--	--	--	4.4
25.25 and larger	--	--	--	3.8	1.1	--	2.4	--	--	2.0	0.9
Disintegrated	32	199	6	--	2	--	4	1	--	100	34.4
Total	6,548.5	9,374.8	6,874.5	7,197.3	5,560.2	9,074.5	5,619.4	5,887.0	3,121.5	6,060.4	6,531.8

TABLE 11

SARDINE LARVAE—CO-OCCURRING WITH ANCHOVY LARVAE: AVERAGE NUMBER PER POSITIVE HAUL (× 10²), SUMMARIZED BY SIZE AND YEAR, 1951–60

Size class (mm)	Year										Un-weighted average
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	
3.0	1,953	2,648	1,718	2,747	1,492	4,068	969	1,784	1,078	1,763	2,022.0
4.75	1,833	2,557	2,602	2,252	2,135	2,321	811	1,567	816	1,422	1,831.6
5.75	1,005	776	680	869	1,028	917	1,130	934	442	901	868.2
6.75	655	809	535	446	309	682	367	629	167	641	524.0
7.75	678	740	480	379	185	655	293	675	109	422	461.6
8.75	512	529	268	300	128	638	339	318	123	445	359.5
9.75	397	421	136	294	167	537	296	178	98	375	289.9
10.75	304	364	107	362	101	325	227	90	90	230	220.0
11.75	285	267	146	262	112	209	134	77	45	214	175.1
12.75	220	233	143	223	104	197	45	53	39	112	136.9
13.75	187	166	104	190	84	84	65	29	40	46	99.5
14.75	129	107	68	156	76	106	108	22	12	38	82.2
15.75	71	62	46	81	48	132	68	27	9	11	55.5
17.25	102.5	44.0	57.3	54.0	44.8	69.9	47.6	15.8	10.5	4.1	45.0
19.25	16.5	19.8	11.6	21.3	16.2	24.2	9.7	7.1	2.1	--	12.8
21.25	35.0	14.0	6.8	2.2	4.2	15.2	9.5	2.2	--	2.1	9.1
23.25	22.4	4.0	3.4	8.0	--	5.6	3.0	--	--	--	4.6
25.25 and larger	--	--	--	6.2	1.7	--	3.8	--	--	2.3	1.4
Disintegrated	46	232	8	0	4	0	2	2	0	106	40.0
Total	8,451.4	9,992.8	7,120.1	8,652.7	6,039.9	10,985.9	4,927.6	6,405.1	3,080.6	6,734.5	7,239.1

The problem then is to account for the higher number of each species in hauls in which they co-occurred—to determine whether they were obtained in centers of heavier spawning for both species or whether survival was better in areas of co-occurrence. If the latter were true, it would be difficult to justify any hypothesis that postulates that competition between the two species would adversely affect their survival.

The average numbers of larvae per positive haul are summarized by size and year in Tables 10 to 15. For each species these data are summarized in three ways: (1) for all occurrences, (2) for hauls in which the larvae of one species co-occurred with those of the other, and (3) for hauls in which the larvae of a species occurred alone.

A semi-log plot (Figures 11 and 12) gives a simple method of illustrating changes in abundance with

TABLE 12

SARDINE LARVAE—OCCURRING ALONE (NO ANCHOVY LARVAE): AVERAGE NUMBER PER POSITIVE HAUL (× 10^2), SUMMARIZED BY SIZE AND YEAR, 1951–60

Size class (mm)	Year										Un-weighted average
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	
3.0	810	2,604	1,922	1,276	1,217	1,257	1,826	222	1,580	1,059	1,377.3
4.75	357	2,619	2,237	1,562	1,236	2,306	1,552	505	952	201	1,352.7
5.75	249	1,307	859	746	820	696	712	510	228	142	626.9
6.75	166	503	266	346	436	201	448	465	140	66	303.7
7.75	129	298	158	267	340	198	699	326	62	83	256.0
8.75	72	212	183	199	154	198	407	226	57	25	173.3
9.75	83	149	101	144	132	158	318	171	82	29	136.7
10.75	48	78	192	73	78	146	286	68	57	--	102.6
11.75	51	71	72	42	74	61	204	68	38	36	71.7
12.75	31	48	120	33	69	54	173	27	91	44	69.0
13.75	47	44	61	42	58	99	50	13	42	28	48.4
14.75	34	74	56	34	59	47	18	9	26	--	35.7
15.75	13	21	43	10	29	38	14	34	28	--	23.0
17.25	19.6	43.9	46.6	6.2	36.4	89.8	39.2	48.1	27.0	--	35.7
19.25	19.6	43.6	10.7	6.0	9.5	84.8	38.9	12.2	14.0	--	23.9
21.25	3.3	13.0	--	4.5	3.3	62.9	--	--	14.0	--	10.1
23.25	8.2	20.2	--	--	--	8.7	--	--	--	--	3.7
25.25 and larger	--	--	--	--	--	--	--	--	--	--	0.0
Disintegrated	0	143	0	0	0	15	6	0	0	63	22.7
Total	2,140.7	8,291.7	6,327.3	4,790.7	4,751.2	5,720.2	6,791.1	2,704.3	3,438.0	1,776.0	4,673.1

TABLE 13

ANCHOVY LARVAE—ALL OCCURRENCES: AVERAGE NUMBER PER POSITIVE HAUL (× 10^2), SUMMARIZED BY SIZE AND YEAR, 1951–60

Size class (mm)	Year										Un-weighted average
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	
2.5	871	2,266	2,356	4,396	3,198	2,611	3,447	4,181	4,791	7,266	3,538.3
3.75	871	1,768	2,974	3,221	4,724	3,964	4,076	5,476	5,104	5,536	3,771.4
4.75	1,081	1,380	2,611	2,625	2,789	2,885	3,432	3,493	2,688	4,240	2,722.4
5.75	1,164	1,540	1,852	2,564	3,009	2,732	3,156	3,317	2,412	3,624	2,537.0
6.75	1,107	1,471	1,592	2,637	2,554	3,120	2,956	2,837	2,173	2,908	2,335.5
7.75	723	1,267	1,182	1,925	2,052	2,818	2,515	2,243	1,809	2,006	1,854.0
8.75	453	846	891	1,418	1,573	2,306	2,055	1,680	1,349	1,340	1,391.1
9.75	303	561	676	913	1,112	1,857	1,451	1,135	1,031	928	996.7
10.75	187	370	424	581	712	1,273	888	764	702	578	647.9
11.75	144	241	268	376	388	751	558	494	407	391	401.8
12.75	76	135	129	239	237	402	312	311	277	243	236.1
13.75	43	74	88	132	136	194	162	177	181	154	134.1
14.75	28	64	51	84	85	100	101	109	120	115	85.7
15.75	19	43	30	49	49	51	54	65	92	63	51.5
17.25	13.7	62.9	35.2	40.2	66.8	57.8	67.5	67.0	91.3	81.3	58.4
19.25	4.3	28.4	12.5	23.5	23.4	40.5	16.8	29.1	37.8	36.8	25.3
21.25	2.6	20.9	7.8	4.4	7.0	2.8	11.3	8.9	9.9	9.5	8.5
23.25 and larger	12.3	13.7	11.6	4.2	8.6	7.4	6.8	3.1	3.0	11.4	8.2
Disintegrated	106	23	21	36	27	4	13	10	88	378	70.6
Total	7,208.9	12,174.9	15,212.1	21,268.3	22,750.8	25,176.5	25,278.4	26,400.1	23,366.0	29,909.0	20,874.5

increase in size. Two curves are plotted for each species, one illustrating abundance of co-occurring larvae, the other of the species taken alone.

The two curves for anchovy larvae tend to converge with increase in size. This convergence would be expected if survival were better in hauls in which the larvae of a species occurred alone, free from competition. It is well to remember that the upper curve represents the average of 1,489 hauls and the lower the average of 5,266 hauls—large amounts of data.

Data on changes in relative abundance with increase in size are less consistent for sardines. The upper curve, sardine larvae in co-occurrences with anchovy larvae, necessarily is based on the same number of hauls as is its counterpart graph for anchovies (1,489), but the lower curve is based on considerably

TABLE 14

ANCHOVY LARVAE—CO-OCCURRING WITH SARDINE LARVAE: AVERAGE NUMBER PER POSITIVE HAUL (× 10^2), SUMMARIZED BY SIZE AND YEAR, 1951–60

Size class (mm)	Year										Un-weighted average
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	
2.5	1,524	2,836	2,648	6,773	2,997	2,471	1,326	6,832	11,385	11,189	4,998.1
3.75	1,525	2,600	4,578	4,310	5,877	5,057	3,336	14,634	12,854	8,780	6,355.1
4.75	2,432	2,211	2,509	3,791	3,618	4,818	3,599	9,116	4,655	7,478	4,422.7
5.75	2,282	2,597	2,218	3,415	3,687	4,789	4,741	8,550	4,051	6,920	4,325.0
6.75	1,700	2,608	1,992	3,954	3,723	3,996	4,015	7,138	3,461	5,437	3,802.4
7.75	1,202	2,375	1,445	2,708	3,225	3,364	3,579	5,020	3,011	3,708	2,963.7
8.75	726	1,495	1,016	2,063	2,398	2,702	3,700	3,559	2,607	2,232	2,249.8
9.75	423	934	746	1,406	1,900	1,975	2,879	2,292	2,008	1,313	1,587.6
10.75	236	624	546	859	1,022	1,460	1,819	1,485	1,294	728	1,007.3
11.75	182	354	360	468	644	1,117	1,246	974	690	570	660.5
12.75	60	169	184	261	413	561	619	668	463	325	372.3
13.75	46	69	149	132	226	266	269	381	221	219	197.8
14.75	31	94	99	91	162	163	162	192	156	119	126.9
15.75	9	55	48	44	94	56	94	100	109	45	65.4
17.25	16.2	76.3	51.5	57.6	137.0	84.8	149.9	50.2	69.1	49.8	74.2
19.25	1.4	41.1	12.2	29.2	45.7	25.0	13.0	28.1	34.5	16.1	24.6
21.25	1.8	27.5	4.4	4.9	14.9	--	7.7	11.0	9.5	13.6	9.5
23.25 and larger	--	25.4	17.1	--	13.0	--	7.5	5.8	4.0	--	7.3
Disintegrated	53	27	18	30	28	0	6	5	275	343	78.5
Total	12,450.4	19,218.3	18,641.2	30,396.7	30,224.6	32,904.8	31,568.1	61,041.1	47,357.1	49,485.5	33,328.8

TABLE 15

ANCHOVY LARVAE—OCCURRING ALONE (NO SARDINE LARVAE): AVERAGE NUMBER PER POSITIVE HAUL (× 10^2), SUMMARIZED BY SIZE AND YEAR, 1951–60

Size class (mm)	Year										Un-weighted average
	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	
2.5	607	1,994	2,273	3,343	3,269	2,646	3,945	3,459	3,417	6,711	3,166.4
3.75	607	1,371	2,521	2,739	4,324	3,685	4,250	2,975	3,490	5,077	3,103.9
4.75	536	984	2,640	2,109	2,502	2,392	3,394	1,958	2,277	3,794	2,258.6
5.75	713	1,037	1,748	2,187	2,774	2,206	2,786	1,888	2,071	3,158	2,056.8
6.75	867	930	1,479	2,054	2,148	2,896	2,709	1,663	1,904	2,551	1,920.1
7.75	529	740	1,107	1,579	1,645	2,678	2,267	1,485	1,559	1,766	1,535.5
8.75	342	536	855	1,133	1,286	2,205	1,670	1,168	1,088	1,214	1,149.7
9.75	254	384	657	694	838	1,827	1,117	820	828	873	829.2
10.75	167	250	390	458	604	1,225	670	568	579	557	546.8
11.75	129	187	243	335	299	658	397	363	348	366	332.5
12.75	82	119	114	229	175	362	241	214	239	231	200.6
13.75	42	76	70	132	105	175	137	121	173	145	117.6
14.75	27	50	37	82	58	84	87	87	112	115	73.9
15.75	23	38	26	51	33	50	44	56	89	65	47.5
17.25	12.7	56.5	30.6	32.4	42.4	50.8	48.3	71.6	96.0	85.8	52.7
19.25	5.5	22.4	12.6	21.0	15.7	44.5	17.6	29.4	38.5	39.8	24.7
21.25	2.9	17.7	8.7	4.2	4.2	3.5	12.1	8.3	9.9	8.9	8.0
23.25 and larger	17.3	8.1	10.0	6.1	7.0	9.3	6.6	2.4	2.8	13.1	8.3
Disintegrated	127	22	22	38	27	5	14	12	49	382	69.8
Total	5,090.4	8,822.7	14,243.9	17,226.7	20,156.3	23,202.1	23,812.6	16,948.7	18,370.2	27,152.6	17,502.6

fewer hauls (644). Some of the irregularities in this curve, compared with the other three, may be due to fewer data.

At first glance at the two curves for sardine larvae, one gets the impression that survival may have been somewhat better in the co-occurring hauls. On closer inspection however, it is seen that larvae larger than 6.75 mm followed no consistent trend, except as noted below. The greatest difference in relative abundance was between the smaller larvae (3.0–5.75 mm long) and all larger larvae. This difference could be interpreted as poorer initial survival of sardine larvae in situations where they occur alone. An equally logical explanation for the difference, however, is based on the increasing frequency of co-occurrences of sardine and anchovy larvae with increase in size. It was noted earlier that the frequency of co-occurrence of sardine and anchovy eggs was markedly lower than for larvae. A natural corollary is that newly hatched larvae of the two species would co-occur less frequently than the larger larvae. The effect on abundance curves would be to increase the numbers of larger larvae in hauls in which the species co-occurred than in hauls in which they occurred alone. Furthermore, the two curves for sardine larvae do converge if all larger-sized larvae (17.25–25.25 mm) are taken into account. As many larger larvae were taken in hauls in which sardines occurred alone as in hauls in which both species occurred—0.73 larvae per haul on the average.

Thus, the basic question has been answered; better survival was not indicated by the hauls in which both species were caught even though average numbers of larvae per haul were larger.

Although the analysis has been confined largely to the 1950's, the report can be brought up to date. Tables 3 and 4 include the number of occurrences and co-occurrences of sardine and anchovy larvae during the first 3 years of quarterly cruises, 1961–63. Anchovy larvae occurred in 43 percent of the hauls in 1961, 49 percent in 1962, and 54 percent in 1963. Sardine larvae occurred in 5 percent of the hauls in 1961, 6 percent in 1962, and 9.5 percent in 1963. (Data for 1963 are not closely comparable to those for other years because a number of closely spaced inshore stations were added.) Anchovy larvae occurred in nearly 90 percent of the hauls containing sardine larvae. In contrast, sardine larvae occurred in only 13 percent of the hauls containing anchovy larvae. Co-occurrences of anchovy larvae with sardine larvae were even higher than in the late 1950's, and even a higher percentage of the collections of anchovy larvae contained no sardine larvae. Anchovy larvae now seem to be completely dominant.

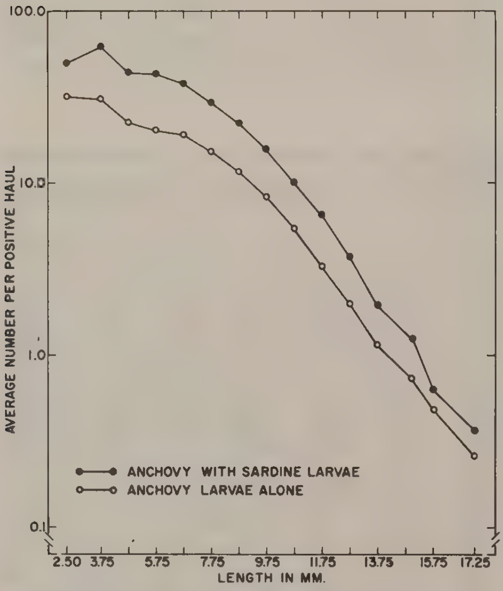

FIGURE 11. Comparisons of average number of anchovy larvae per positive haul as related to length (mm) for 1) hauls containing both anchovy and sardine larvae, and 2) hauls with anchovy larvae alone. Data for 1951–60 combined.

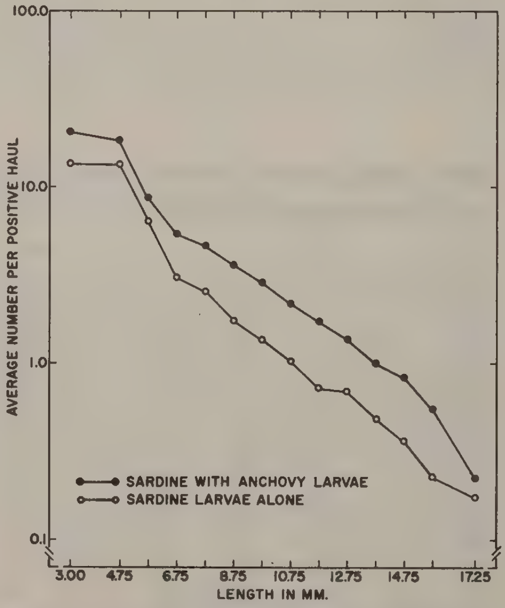

FIGURE 12. Comparisons of average number of sardine larvae per positive haul as related to length (mm) for 1) hauls containing both sardine and anchovy larvae and 2) hauls with sardine larvae alone. Data for 1951–60 combined.

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Use of Population Dynamics in Marine Fishery Studies

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The author provides a challenging exercise which will help the teacher demonstrate the need for mathematics in biology.

Introduction

Since the 1930's the field of population dynamics has become increasingly important to fishery biologists in their attempt to arrest the sharp decline of many of the most important fisheries of the United States. The decreased catches of the Pacific halibut, Pacific salmon, Great Lakes lake trout, Pacific sardine, Atlantic salmon and many other species have required that attention be focused on the life processes of each species prior to establishing corrective management procedures. Mathematical models, which are equations or sets of equations, give quantitative descriptions of these life processes and allow a biologist the insight to initiate the proper regulatory procedures.

The following equation, published by E. S. Russell in 1931, was among the first to describe changes in a fish population:

$$S_2 = S_1 + (R+G) - (C+Q)$$

S_2 = numbers (or weights) of fish at beginning of year 2.
S_1 = numbers (or weights) of fish at beginning of year 1.
R = 1-year-old fish that in the year of age 1 grow large enough to enter the fishery (recruitment).
G = increase in weight of the population due to growth (omitted when numbers are used).
C = numbers (or weights) of fish caught during the year.
Q = numbers (or weights) of fish which die during the year from natural causes (all causes other than fishing).

Although not completely accurate because the factors are interrelated and not additive, this equation provides an adequate example of population dynamics for the student.

Demonstration

By analyzing tag returns as represented by colored beads the student can determine the size of a theoretical fish population (S_1) available to fishermen for harvest. A second more difficult lesson for the student can be the estimate of recruitment (R) and natural deaths (Q) which will predict the number of fish (S_2) available for harvest in the next year. The second lesson will require the use of an exponential table either by the student or teacher. These tables are readily available in most mathematical handbooks.

Materials (for nine students)

1. 5,000 colored beads or balls (6 mm diameter glass beads are ideal).
2. Three lengths of glass tubing of a diameter to accommodate glass beads.
3. Clear plastic tubing.
4. Clamps.
5. Glass jars.

Reprinted from THE AMERICAN BIOLOGY TEACHER, Vol. 29, No. 6, September, 1967

6. Small funnels (the top portion of small polypropylene bottles are suitable).
7. Three small glass containers to hold "fish" samples.
8. Small dipping cup (sampling gear) large enough to remove a sample of about 200 "fish."
9. India ink marking pencil.
10. Data sheets.

Set-up methodology

Each set of 5,000 beads should be purchased or colored as in Table 1.

Table 1. Color scheme of glass beads

Age Groups	Color of Beads	Number of Beads
N_1	Black	2,550
N_2	Yellow	1,020
N_3	Blue	408
N_4	Orange	163
N_5	Grey	66
N_6	Green	24
N_7	Brown	10
N_8	White	5
N_9	Clear	3
Tagged fish	Red	751

Each glass bead represents an individual fish and each color signifies an age group, except for the red beads which indicate tagged fish. The black beads indicate the 1-year-old fish (N_1), yellow indicates the 2-year-old fish (N_2), etc.

The beads should be separated further and placed in jars labeled populations 1, 2, and 3 as indicated in Table 2.

Table 2.
Separation of 5,000 beads into 3 fish populations

Age Group	Color of Beads	Number of Beads Pop. 1	Pop. 2	Pop. 3
N_1	Black	950	850	750
N_2	Yellow	380	340	300
N_3	Blue	152	136	120
N_4	Orange	61	54	48
N_5	Grey	25	22	19
N_6	Green	9	8	7
N_7	Brown	3	4	3
N_8	White	2	2	2
N_9	Clear	1	1	1
Total		1583	1417	1250
Tagged Fish	Red	83	250	417
Total		1666	1667	1667

The 750 red beads are separated into groups of 83, 250, and 417 beads which represent 5%, 15%, and 25% of the initial populations.

Since the students will have to count large numbers of "fish" in this study, it is necessary to employ some sort of counting device. Fig. 1 shows a simple device for counting which can be assembled easily.

The glass beads are poured into a funnel which is connected to a glass tube by a plastic or rubber connector. The tubes are marked at convenient intervals (10 beads) to allow rapid counting. Clear plastic tubing can be clamped on the lower end of the tube as the beads are being counted. After each count is made the clamp is released and the beads drop into the jar. One glass tube per 3 students is a convenient set-up. One student counts, another handles the "fish," and the third records the data. Data sheets should be provided as shown in Figs. 2 and 3.

Procedure for lesson 1

Of the 4 factors needed to determine S_2 only the catch is normally available to fishery biologists. All other factors need to be calculated. The estimate of S_1, for example, is provided by analyzing tag returns. One of the most simple estimates to calculate is the Petersen estimate which is based on the theory that the ratio of numbers tagged (T) to the population size, S_1, is the same as the ratio of tag returns (V) in a sample catch to the sample catch (C), i.e.:

$$\frac{\text{Number tagged (T)}}{\text{Population } (S_1)} = \frac{\text{Tag returns (V)}}{\text{Sample catch (C)}}$$

Solving for S_1:

$$S_1 = \frac{(T)\,(C)}{(V)}$$

This equation produces an accurate estimate of S_1 if the tagged "fish" mix well with the untagged and if several other assumptions are met. Let the students add the 83 tagged "fish" to population 1, 251 to population 2, and 417 to population 3. The population sizes are now approximately equal except that 5% of population 1 has been tagged, 15% of population 2 has been tagged, and 25% of population 3 has been tagged. As the percentage of the total population increases,

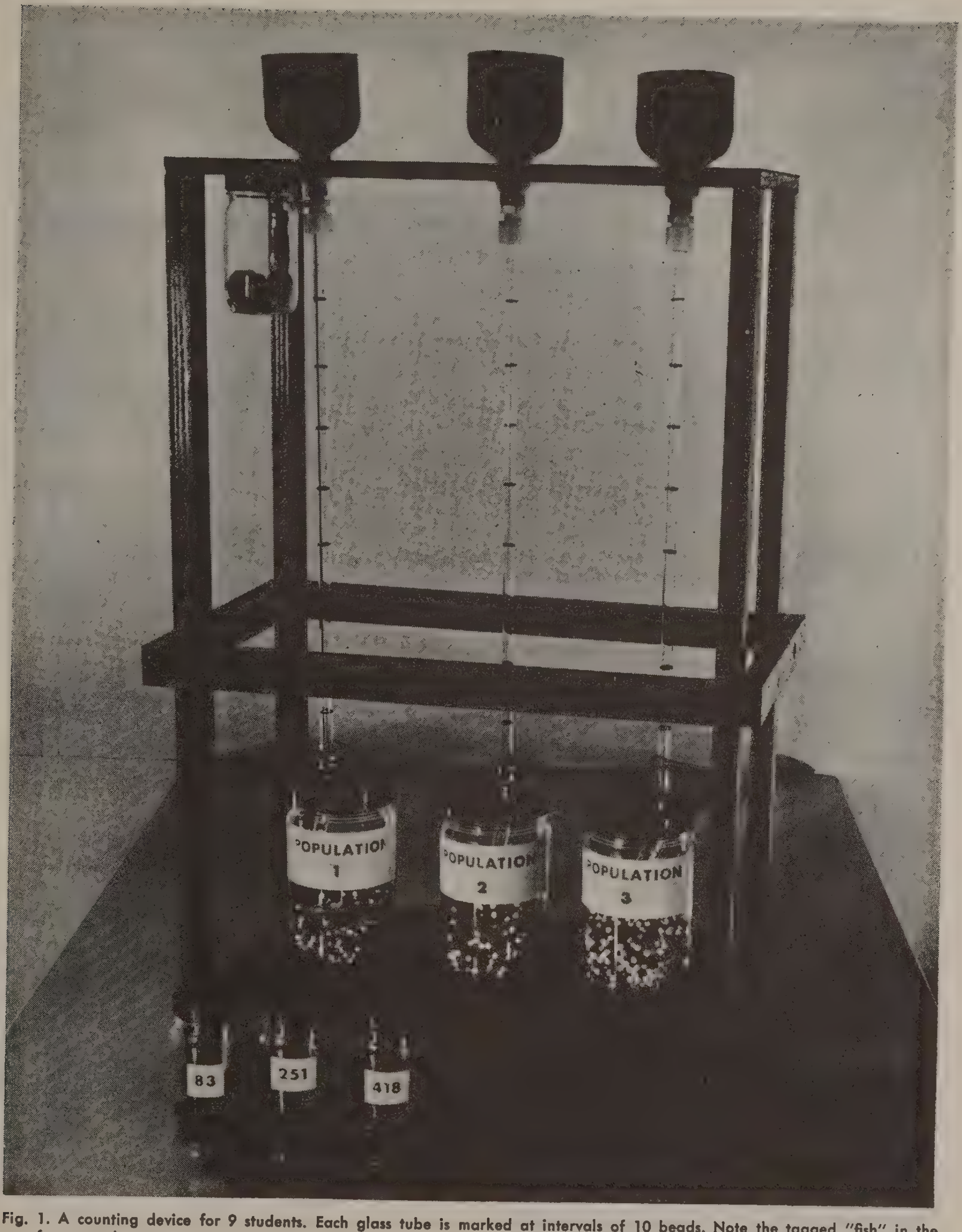
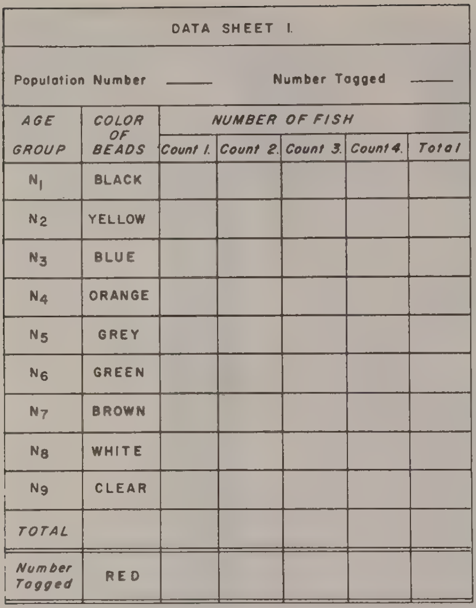

POPULATION 1
POPULATION 2
POPULATION 3
83
251
418

Fig. 1. A counting device for 9 students. Each glass tube is marked at intervals of 10 beads. Note the tagged "fish" in the foreground.

up to approximately 25%, the population estimate improves. After mixing, the same sampling gear should be used in taking a sample from each population so that a nearly equal catch is obtained. A catch of about 200 "fish" gives an estimate of the tagged-to-



DATA SHEET I.

Population Number _____ Number Tagged _____

AGE GROUP	COLOR OF BEADS	NUMBER OF FISH				
		Count 1.	Count 2.	Count 3.	Count 4.	Total
N_1	BLACK					
N_2	YELLOW					
N_3	BLUE					
N_4	ORANGE					
N_5	GREY					
N_6	GREEN					
N_7	BROWN					
N_8	WHITE					
N_9	CLEAR					
TOTAL						
Number Tagged	RED					

Fig. 2. Data sheet for counting beads in the sample catch. A sheet should be furnished to each group of three students.

untagged ratio if the "fish" have been well mixed. For the first lesson, only the tagged fish (red beads) and the untagged fish (all other beads) need be counted.

Procedure for lesson 2

While the fishery is being sampled to determine the number of tags present, the number of "fish" per age group can also be found. The number of "fish" in the first age group affords an estimate of recruitment. The percentage of 1-year-old "fish" (N_1) in the sample multiplied by the population estimate (S_1) gives an estimate of recruitment (R) for the next year. The decrease in number per age group in turn gives an estimate of the total mortality in the population, a statistic which must be found in order to estimate deaths due to natural causes. We assume that our given population of "fish" decreases evenly with time at a rate proportional only to the population size at that time. In other words the "fish" are dying at an exponential rate. Fig. 4 shows this decrease diagrammatically. The number of fish at any age decreases in a year to the number of fish in the previous year multiplied by e^{-i} where e is a constant number, 2.718, and i is the total mortality rate. For example:

$$N_3 = N_2 e^{-i}$$

and $$\frac{N_3}{N_2} = e^{-i}$$

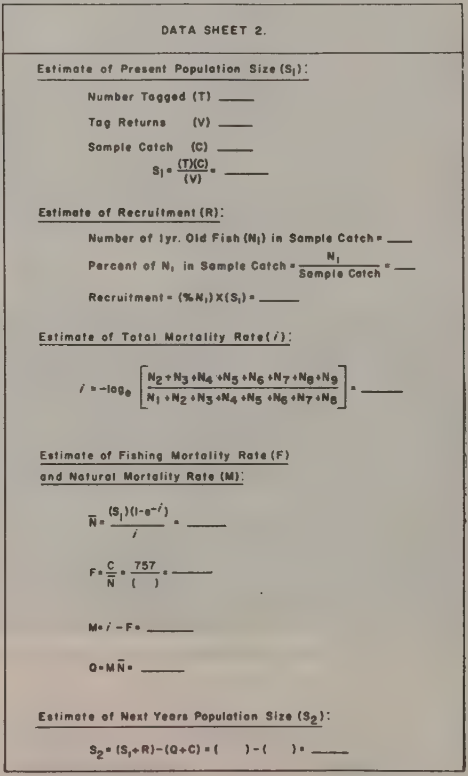
Using the entire age composition data as obtained from counting the colors in the sample catch, and using the following equation, we get our best estimate of e^{-i}, i.e.:

$$\frac{N_1+N_2+N_3+N_4+N_5+N_6+N_7+N_8}{N_2+N_3+N_4+N_5+N_6+N_7+N_8+N_9} = e^{-i}$$

From a table of exponential functions and knowing the value for e^{-i}, the value of i can be found. If a table of exponential functions is not readily available, a table of natural logarithms may be used, i.e.:

$$-\log_e \left[\frac{N_2+N_3+N_4+N_5+N_6+N_7+N_8+N_9}{N_1+N_2+N_3+N_4+N_5+N_6+N_7+N_8}\right] = i$$

The total mortality of the fishable population



DATA SHEET 2.

Estimate of Present Population Size (S_1):

Number Tagged (T) _____

Tag Returns (V) _____

Sample Catch (C) _____

$$S_1 = \frac{(T)(C)}{(V)} = \_\_\_\_\_$$

Estimate of Recruitment (R):

Number of 1yr. Old Fish (N_1) in Sample Catch = _____

$$\text{Percent of } N_1 \text{ in Sample Catch} = \frac{N_1}{\text{Sample Catch}} = \_\_\_\_\_$$

Recruitment = (% N_1) X (S_1) = _____

Estimate of Total Mortality Rate (i):

$$i = -\log_e \left[\frac{N_2+N_3+N_4+N_5+N_6+N_7+N_8+N_9}{N_1+N_2+N_3+N_4+N_5+N_6+N_7+N_8}\right] = \_\_\_\_\_$$

Estimate of Fishing Mortality Rate (F)
and Natural Mortality Rate (M):

$$\bar{N} = \frac{(S_1)(1-e^{-i})}{i} = \_\_\_\_\_$$

$$F = \frac{C}{\bar{N}} = \frac{757}{(\quad)} = \_\_\_\_\_$$

$$M = i - F = \_\_\_\_\_$$

$$Q = M\bar{N} = \_\_\_\_\_$$

Estimate of Next Years Population Size (S_2):

$$S_2 = (S_1+R)-(Q+C) = (\quad)-(\quad) = \_\_\_\_\_$$

Fig. 3. Data sheet for calculating estimates of S_2.

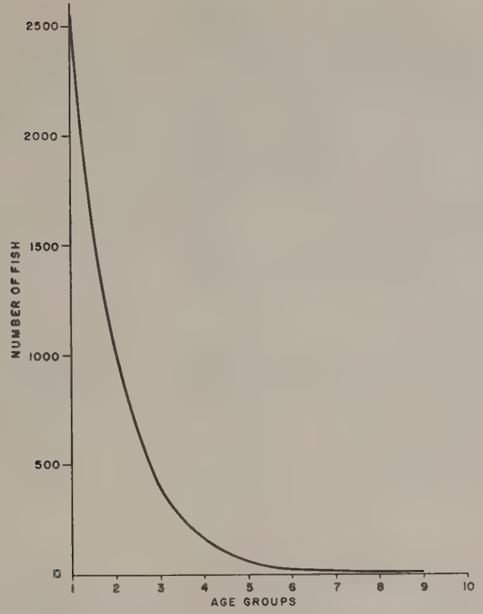


Fig. 4. Exponential decrease in a fish population from an initial abundance of 2,550 at age 1 when the mortality rate is 92%.

is composed of mortality due to fishing (F) and that due to all other causes, termed natural mortality (M). The number dying due to natural causes (Q) equals the natural mortality rate multiplied by the average population, i.e.:

$$Q = M\overline{N} \text{ where } \overline{N} = \frac{S_1 (1-e^{-i})}{i}$$

Also, the number of fish caught is equal to the fishing mortality multiplied by the average population, i.e.:

$$C = F\overline{N}$$

Assume the total catch to be 757 fish for the year; then knowing i, Q can be determined since:

$$F = \frac{C}{\overline{N}}$$
$$i - F = M$$
$$\text{and } Q = M\overline{N}$$

Expected Results

Since we are dealing with numbers and not weights of fish, S_2 now can be readily calculated and should equal about 1,667 since:

$$S_2 = (S_1 + R) - (Q + C)$$

$S_1 = 1{,}667$
$R = 1{,}000$
$i = 0.916 = 91.6\%$
$\overline{N} = 1{,}092$
$C = 757$
$F = 0.693 = 69.3\%$
$M = 0.223 = 22.3\%$
$Q = 244$

This routine enables fishery biologists to make limited predictions of fish catch, although predictions are sufficiently accurate for management of only a few species. The effects of environmental factors on the success of reproduction and survival play far too great a role and are usually unpredictable. The approach is correct, however, and in time more sophisticated models will be available to allow prediction with increasing accuracy. Already, the effects of fishing and the environment on the Pacific halibut stocks have been predicted and the fishery has been managed so well that greater catches are being realized without an increase in effort. Other fisheries such as yellowfin tuna and salmon are also being managed more effectively today than ever before through the study of population dynamics. Russell's equation was a start, and remains as an example of the use of population dynamics in studying marine fisheries.

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Lagler, K. F. Freshwater fishery biology. 1956. Wm. C. Brown Company, Dubuque, Iowa, 421 pp. (Chapter 12 explains several methods of estimating population sizes, but note pages 170 and 171 in particular.)

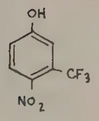
Ricker, W. E. Handbook of computations for biological statistics of fish populations. 1958. Fish. Res. Bd. Canada Bull., No. 119, 300 pp. (Note pages 17 through 28 and 81 through 100.)

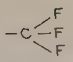
Rounsefell, G. A., and W. H. Everhart. Fishery science: Its methods and applications. 1953. John Wiley and Sons, Inc., New York, 444 pp. (A description of the Petersen estimate is given on pages 90 and 91.)

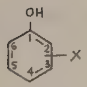
RESEARCH REPORTER

MOLECULAR CHARACTERISTICS VERSUS BIOLOGICAL ACTIVITY

The molecular characteristics of mononitrophenols containing halogens not only play a key role in their biological activity but provide a novel example of selective toxicity among vertebrate animals.


TFM


Trifluoromethyl group


X=F, Cl, Br, CF_3 in the 2 or 3 position

It has been reported that efforts to control the parasitic sea lamprey in the Great Lakes are directed at present to the applications of a selective toxicant to streams inhabited by lamprey larvae (CHEMISTRY, May 1966, page 10). Since 1961, the larvicide that has been used almost exclusively in the control program has been 3-trifluoromethyl-4-nitrophenol (TFM). However, this is only one of about 15 closely related compounds, all halogen-containing mononitrophenols, that display a selectively toxic action upon lampreys. Although not all of the halogenated mononitrophenols are selectively toxic to lampreys (in fact, fewer than half of those tested), no other group of related compounds has displayed any useful larvicidal activity except for the substituted nitrosalicylanilides.

The group of compounds with the desired selectively toxic properties is a small class of closely related chemicals. These compounds are phenols containing a single nitro group in the 4-position and halogens or a trifluoromethyl group substituted directly on the ring in the 2- or 3-position. The most desirable substances from a practical standpoint are those having a single halogen or a trifluoromethyl group in the 3-position. The trifluoromethyl group is more effective than halogen atoms. Among the halogens, bromine and chlorine are somewhat more effective than fluorine. Large numbers of iodonitrophenols were not tested, for these compounds are notoriously unstable and presumably would not have been suitable for either bioassays or practical application. The lack of availability of compounds related to 3-nitrophenol precluded extensive investigation of this structure.

Figure 2. Large chemical proportioning pump. Attendant is replenishing concentrated stock solution of toxicant that is premixed with water drawn from the river and then returned to the river

Figure 1. A small chemical proportioning pump contrived from an automobile carburetor and battery feeds concentrated stock solution of TFM into a small tributary of a larger river

All of the trifluoromethyl, monohalogen, and dihalogen derivatives of 4-nitrophenol studied were significantly more toxic to lamprey larvae than to fishes. This was not the case with the tri- and the tetrahalogen-4-nitrophenols tested. These were much more toxic to fish than to lamprey larvae. Furthermore, these compounds killed fish at much lower concentrations than did any of the mono- or disubstituted 4-nitrophenols. It appears that the addition of more than two halogen atoms results in an "overloading" of the molecule with such a pronounced increase in the toxic effect upon fishes that the compounds become more toxic to these than to lampreys.

Among the monosubstituted derivatives of 4-nitrophenol, the monofluorine derivatives are the least toxic and show a narrower differential toxicity than other members of this group. There is little difference among the chlorine and the bromine derivatives. They are significantly more toxic than the fluorine compounds and show a more pronounced differential toxicity. There is

A reprint from Chemistry

Vol. 40, October 1967, Pages 28-30
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no consistent change in toxicity among any of the pairs of halogen-4-nitrophenols when the halogen is moved from the 2- to the 3-position.

In contrast to the fluorine, chlorine, and bromine compounds, the trifluoromethyl-4-nitrophenols show a marked difference in effect associated with the position of the trifluoromethyl group. When this group is in the 2-position, the compound is intermediate between the fluoro and the chloro analogs, both in general toxicity and differential toxicity between lampreys and fishes. When the trifluoromethyl group is in the 3-position, however, the concentration required to kill essentially 100% of the lampreys drops to 2 p.p.m. (parts per million). But even when concentration reaches 9 p.p.m., only 25% of the test fishes are killed. The differential toxicity factor thus rises to the relatively high value of 4.5. This combination of properties is responsible for the widespread use of 3-trifluoromethyl-4-nitrophenol (TFM) in sea lamprey control.

A total of 17 substituted 2-nitrophenols were tested. Of these, only three are selectively toxic to lampreys, 10 are selectively toxic to fish, and three are biologically inactive. One compound is equally toxic to both fish and lampreys. It is interesting to speculate that this difference between the 2-nitrophenols and the 4-nitrophenols might somehow be related to the possibility of strong intramolecular hydrogen bonding between the nitro and hydroxyl groups in the 2-nitrophenols which is absent in the 4-nitrophenols.

In no instance did any phenol that varied from a structure containing one nitro group and one or more halogens possess any indication of the desired selective toxicity. Phenol itself was more toxic to fish than to larval lampreys. Twenty of 22 monohalo-, polyhalo-, and mixed polyhalophenols were similar in this regard; pentachlorophenol was equally toxic to all test animals and pentabromophenol had no toxic effect on any species. The three mononitrophenols and 2,4-dinitrophenol were biologically inactive at a concentration of 5 p.p.m. Six of the seven mono-, halo-, di-, and trinitrophenols subjected to the same screening tests were inactive; the exception was 2-chloro-4,6-dinitrophenol which was toxic to fish but not to lampreys. The only mixed halonitrophenol examined was 4-bromo-2-chloro-6-nitrophenol; it was more toxic to fish than to larval lampreys.

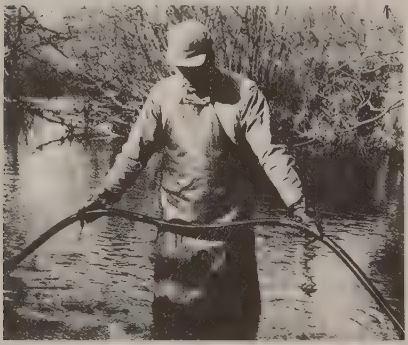


Figure 3. Perforated pipe discharges TFM mixture into a small tributary of Lake Michigan

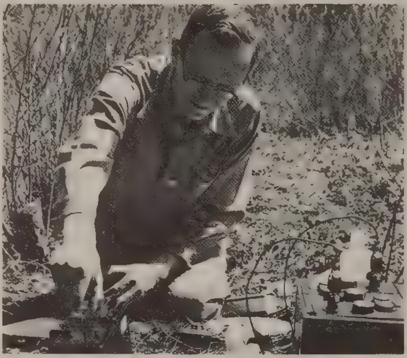
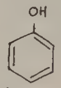
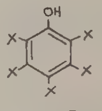


Figure 4. Colorimetric analysis for nitrophenol content of stream water. Since this picture was taken mobile laboratories have become available, but the primitive conditions of the northern Great Lakes region remain unchanged and still provide a challenge to chemists who must control stream treatments by these techniques

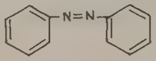
In view of the widespread occurrence of oxidation-reduction processes in living systems, it would be interesting to investigate the biological activity of oxidation or reduction products of the selectively active 4-nitrophenols. The availability of such compounds is limited and extensive testing has not been carried out. Of the possible oxidation or reduction products which were tested—for example, halogenated resorcinols, quinones, azobenzenes, and anilines—many were biologically inactive and none was more toxic to lampreys than to fish.



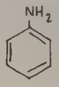
Phenol



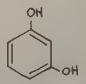
Pentahalophenol



Azobenzene



Aniline



Resorcinol

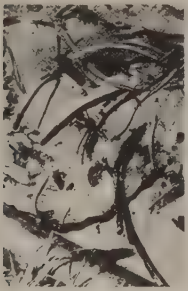
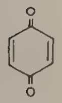


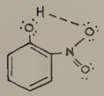
Figure 5. The work of TFM. These are dead and dying larval sea lampreys lying on a sandy shoal in the Silver River, a tributary of Lake Superior

The importance of molecular dimensions among biologically active chemicals is well established for herbicidal compounds, and the position of substituent groups is significant in certain molluscicides. Either size or structure or some combination of these or other properties of the molecule may be responsible for the selectively toxic action of the halonitrophenols upon lampreys. Unfortunately, knowledge of the precise effect of these compounds on lampreys and fishes is still incomplete. There are strong indications that lampreys exposed to TFM die of a complex of circulatory and respiratory failures. Severe vasodilation sufficient to induce a state of acute hypotension (shock) is one of the symptoms observed. This may possibly be attributed to the presence of the nitro group in TFM, for nitrites are vasodilators. In contrast, rainbow trout exposed to high concentrations of TFM exhibit the classic symptoms of anoxia (suffocation) in fishes until the time of their death. Vasodilation in trout is apparently restricted to the gills and is not evident elsewhere in the circulatory system; severe hypotensive effects are not induced in these fishes. It has been suggested that the differential susceptibility of the two species is due to a greater permeability of the respiratory membranes to the chemical in the larval lampreys than in the rainbow trout as well as to a more generalized and more specific toxic effect throughout the lamprey's whole vascular system. It is also probable that other more subtle pathological conditions of a metabolic nature may also exist and contribute to both the general and selectively toxic properties of the halonitrophenols.

These compounds for controlling the sea lamprey represent the first known selective toxicants discovered and used to destroy a particular vertebrate without harming other vertebrate or invertebrate animals occupying the same habitat.



Quinone



Hydrogen bonding
in 2-nitrophenol

Vernon C. Applegate, U.S. Bureau of Commercial Fisheries, Sandusky, Ohio, and Manning A. Smith and Bennett R. Willeford, Bucknell University, Lewisburg, Pa.

Suggested Reading

Applegate, Johnson, and Smith, "The Relation between Molecular Structure and Biological Activity among Mononitrophenols Containing Halogens," Great Lakes Fishery Commission, *Tech. Bull. No.* **11**, pp. 1–20, December 1966.

SALMON OF THE NORTH PACIFIC OCEAN—PART IV SPAWNING POPULATIONS OF NORTH PACIFIC SALMON

4. PACIFIC SALMON IN THE UNITED STATES

by
C. E. Atkinson, J. H. Rose, and T. O. Duncan
U. S. Bureau of Commercial Fisheries Biological Laboratory
Seattle, Washington, January 1966

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INTRODUCTION

Five species of salmon (genus *Oncorhynchus*) occur along the Pacific coast of the United States. Although salmon range from California to Alaska, the freshwater distribution of the individual species varies considerably and, with a few exceptions, is related to the physical characteristics of the streams. Lakes are required to support runs of sockeye salmon (*O. nerka*). Chinook salmon (*O. tshawytscha*) and coho salmon (*O. kisutch*) live for some time in streams before migrating to sea, and require rather stable stream conditions for their maintenance. Pink salmon (*O. gorbuscha*) and chum salmon (*O. keta*) spawn close to the ocean, and the young migrate to sea soon after emerging from the gravel; they can survive in streams subjected to extreme floods and other physical disturbances.

The numbers of salmon which enter any stream to spawn usually vary widely from year to year. This variability in numbers of returning salmon is due to both the effect of natural factors in fresh water and the ocean and to the effect of the fishery upon the stocks. Salmon runs frequently follow definite cycles of abundance which may continue for many years and then suddenly shift to a new series of cycle years.

In some areas the time at which salmon enter the rivers to spawn has changed because of construction of dams, effect of fishing seasons, or for other causes.

Artificial factors have changed the freshwater distribution of salmon and will cause future changes. As an example, the construction of the Grand Coulee, Shasta, and other dams has considerably reduced the distribution of salmon. In other areas, streams have been opened to salmon by laddering falls and other obstacles. Hatchery-reared salmon have been released in streams where salmon did not previously occur, and stable runs have been established which modify the geographical distribution of salmon.

As the scientist reviews the studies of salmon, he is continually confused by reference to spawning in certain areas of a river, the location of particular stocks, or the centers of abundance of fish. The habitat of the Pacific salmon varies widely throughout the range, and frequently significant numbers of salmon spawn in streams which are unnamed and rarely found on the standard available maps. Information is needed on the importance of one stream to the relative abundance of salmon as a whole in that same area, the locations of hatcheries and dams, the time when various salmon runs enter the streams to spawn, and related information. The deliberations of the International North Pacific Fisheries Commission only emphasize this need. This report provides an index to salmon spawning areas on the Pacific coast of the United States and a series of location charts; it should serve as a reference for individuals working on salmon research or management.

The compilation and presentation of this material has required the help of many people intimately acquainted with the salmon streams and population characteristics of local areas. A list of contributors is given in Table 1[1].

Received for publication April 1966. Original, English.
Source: Joint reporting team, Committee on Biology and Research. INPFC Document No. 863.
Bull. 23, Int. North Pac. Fish. Comm., 1967.

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[1] Tables and figures of this report follow the text, beginning on page 48.

Our thanks are due Dr. Leroy Nordby, who assisted in compiling the information. Miss Virginia Coleman, Mr. James Smith, and Mr. James Bruce prepared the charts. Special credit is due Miss Lorraine Kissack for her extensive editorial work and her compilation of Tables 3 and 4.

INCOMPLETENESS OF INFORMATION

Although most areas are regularly patrolled by management agencies, and indices of abundance obtained for the important salmon streams, there are a few areas in the United States where data are either fragmentary or completely missing. This statement applies especially to small streams along the Arctic coast of Alaska and in the Aleutian area. A number of minor streams entering the Bering Sea and those on the Alaska Peninsula contain small runs of salmon, but, because of their isolation or inaccessibility, are not regularly observed. It is hoped that one of the results of publication of this material will be the gradual addition of information now lacking on the distribution of salmon in the United States.

RANGE OF SALMON DISTRIBUTION

The relative importance of the runs is indicated in Figure 1 by the size of the average catch over a period of 25 years (1936–1960). The centers of abundance vary according to species, and even within species. Centers of greatest abundance for sockeye are in Bristol Bay, Kodiak, Cook Inlet, and Puget Sound. Pink salmon ranks on the average as the most abundant species in the U.S. commercial fisheries ; sockeye, chum, chinook, and coho salmon follow in decreasing order of importance.

The distribution of salmon in the coastal waters of the United States extends as far south as southern California. Hubbs (1946) reported pink salmon, chinook salmon, and coho salmon from La Jolla, California. Snyder (1931) reported that chum salmon enter the Klamath River in the northern part of the state. There are no records of sockeye salmon from California coastal waters ; the southern limit of range for this species appears to be along the coast of Oregon.

Records of the occurrence of salmon along the Arctic coast are limited to two species, chum salmon and pink salmon (Wohlschlag, 1956) taken in the vicinity of Point Barrow. Chinook, coho, and sockeye salmon occur in the coastal waters in Kotzebue Sound, but there are no records indicating their presence farther north in the Arctic Ocean (Fiscus, 1955).

Pacific salmon also occur in waters beyond the northern and southern boundaries of the United States. Coho salmon have been reported by Scofield (1937) to occur as far south as Los Coronados Islands (Baja California), Mexico. Both chum and pink salmon are found in Arctic waters as far east as the Mackenzie River, Yukon Territory, Canada (Dymond, 1940).

Because of the extensive and variable movements of salmon in the sea, a better picture of the continental distribution is given by a review of the location of the spawning grounds. The southern and northern continental limits of the spawning areas of the five species of salmon are summarized in Table 2. Although straying has been reported beyond these limits, only evidence of established runs has been used to define the range of salmon in this review.

SPAWNING STREAMS

This report presents information on approximately 3,000 salmon spawning streams in the United States, extending from inter-tidal areas used by pink and chum salmon in Alaska to tributaries of large rivers such as the Yukon, Columbia, and Sacramento. Figures 5 to 110 show in as much detail as possible the actual location of the stream sections used by spawning salmon, the time of spawning, dams, hatcheries, and other pertinent features. The subarea divisions and grid coordinates used in Figures 5–110 are shown in Figures 2 and 3, respectively. Figure 4 is a key to the symbols used. Table 3 is a key to the occurrence of subareas and coordinates in the figures ; Table 4 is a key to the occurrence of coordinates in the subareas. Appendix I is an alphabetical index to the rivers, lakes and streams shown on the maps as well as to the many streams which could not be shown because of space limitations. In some areas of Alaska, streams were numbered to allow better coverage on the maps and also because many of them are unnamed. A numerical listing is given in Appendix II.

The area used by salmon for spawning varies widely between streams ; in some the salmon disperse generally and in others they concentrate densely in well-defined areas. A coloured line parallel to the stream (in Figures 5–110) indicates the section used for spawning except that in some Alaskan streams the exact location of spawning is not known ; for these streams the line indicates only that it is used and not necessarily the specific spawning areas.

Table 5 shows the number of streams used by each species of salmon in the United States. Chum and pink salmon use the greatest number of streams ;

coho, chinook, and sockeye follow in lesser numbers.

TIME OF SPAWNING

The time at which salmon arrive on the spawning grounds is amazingly consistent; it varies only a few days from year to year. Certain factors, however, do occasionally influence the time of arrival. The fishery takes its salmon from certain parts of a run and thus changes the pattern of the run as it arrives on the spawning grounds. Oceanographic conditions, especially above-average temperature, have been reported to affect the timing of salmon runs (Int. Pac. Salm. Fish. Comm., 1959). If the time of arrival on the spawning grounds is distorted too much, poor survival of eggs and fry may result (Int. Pac. Salm. Fish. Comm., 1960). As far as information is available, the peak months of spawning for each species are shown on the maps.

NUMBERS OF SALMON

Spawning escapements have been used for many years by management agencies for the regulation of salmon fisheries along the Pacific coast of the United States. The ideal is to obtain an accurate total count of spawners in each stream; such information is most difficult to obtain (Atkinson, 1944). The numbers of salmon ascending a river to spawn may be estimated or " indexed " by counts made at fishways of dams or at weirs. In either case, fish must swim almost singly over a light-colored " identification " area in order to be counted.

Counts at dams are not complete because some spawning can occur below the dam and fish bound for various streams above are mixed. Fish which pass through navigation locks during lockages are not counted. Also, there is evidence that some fish drop back over dams after having been counted once and are counted again when they resurmount the dam. Therefore, counts at dams are usually only an " index " of the run, not the ideal total count.

It has been possible to install weirs in only a few areas because of the expense, problems of debris and floods, and the possibility of delaying the passage of salmon to the spawning grounds. Weirs occasionally develop holes or " leaks " which allow salmon to ascend undetected, and thereby introduce an unknown error into the counts. The installation of weirs is usually limited to a few major salmon-producing streams, a series of smaller " index " streams, or to controlled research areas. A summary of the total counts obtained at major dams and weirs is given in Tables 6 through 10.

Management agencies have had to depend on semiquantitative indices as a measure of escapement. These estimates, based on counts of live fish observed on spawning grounds, were obtained formerly by foot or boat and more recently by airplane and counting towers (Eicher, 1953; Becker, 1962). Counts of live fish are but a small part of the total run; weather conditions, turbidity, the shifting ratio of live and dead fish, and the individual bias of the observers make them difficult to standardize.

In a few areas estimates have been considerably improved by tagging or other studies which indicate the true magnitude of the runs and provide a basis for correction.

On the basis of experience, observers recognize the relative abundance of spawners necessary to maintain the runs of salmon. They can detect a full distribution of spawners over spawning areas, or evidence of over-crowding. This information, though not quantitative, is used effectively as a comparative index of spawning intensity for management purposes.

Major spawning streams have been indicated on our maps by a red star for escapements averaging 50,000 or more salmon. Unfortunately, this designation by stream does not represent the importance of the combined total escapement of pink and chum salmon from the hundreds of small, short streams in southeastern Alaska, Prince William Sound, and other areas.

DAMS AND OBSTRUCTIONS

One of the most serious problems facing the salmon industry along the Pacific coast of the United States has been the construction of dams on many salmon streams. The height and design of the dams have generally posed varying problems to the passage of adults to the spawning grounds and the descent of young on their way to the sea. Millions of dollars for research and the construction of adequate fish-passage facilities have given assurance that the runs of salmon above most of the dams can be maintained. However, the effect of dams on the survival of the salmon, the change in environmental conditions, and the distribution pattern of the various runs of salmon are not yet completely known.

High dams such as Grand Coulee (Columbia River) and Shasta (Sacramento River) have been built without fishways. Other dams, such as Swan Falls (Snake River), with ineffective fishways have cut off former spawning areas and directly limited the range of salmon. Most dams on the Columbia, Snake, and Sacramento Rivers, and on the smaller rivers, do have fish-passage facilities that allow salmon access to their native spawning grounds (Table 11). Fishways have been constructed over natural rapids or falls (Table 12) and at certain man-made obstacles such as highway bridges and culverts to open up new areas to salmon spawning. Only fish-passage facilities at dams and obstructions on major salmon spawning streams are listed in Tables 11 and 12, or shown on the maps. A recent study by Weber (1965) shows that there is a total of 167 dams and 129 natural obstructions on Pacific coast streams that have fish-passage facilities at the present time. Some of these facilities are so recent as to have made our maps somewhat out of date before they could be printed.

Although it would be useful to know the efficiency of the various fish-passage facilities, this information is not yet available from present studies. We only know that large numbers of salmon successfully pass over the dams and that spring runs of chinook salmon ascending to the headwaters of the Columbia River are being maintained or even increased (U.S. Bureau of Commercial Fisheries, 1958a).

HATCHERIES

For over 85 years the U.S. Government has supplemented the production of salmon by the operation of hatcheries. The first hatchery was built at McCloud River (California) in 1873. Soon afterwards, in 1876, a hatchery was built at Clackamas, Oregon. The number of hatcheries increased rapidly until 1925, then decreased until after World War II. The operations of the various hatcheries are shown in Table 13. At present, 64 hatcheries are being operated by state and federal agencies for rearing Pacific salmon (Table 14) of which 24 have been built since 1950, mainly to offset damage to fish runs caused by the construction of dams.

RANGE AND AREAS OF MAXIMUM ABUNDANCE OF INDIVIDUAL SPECIES

Chinook Salmon

The southern limit of the range of chinook salmon is the San Joaquin River in California. At present, the Sacramento River is a very important producer of chinook salmon ; the salmon runs have increased in recent years due to the release of cooler water from Shasta Dam above the spawning areas. Historically, the Columbia River has been the major producer of chinook salmon, and it is especially noted for the high commercial quality of its spring run. In the last 25 years a series of dams has been built on the Columbia River which could be partially responsible for a decline in the relative importance of this stream. Chinook salmon provide an important fishery in the area around the Gulf of Alaska and especially southeastern Alaska. There has been a small but productive fishery for chinook salmon on the Yukon River. The northern range for chinook salmon is probably the Unalakleet River (Norton Sound), although there are unconfirmed reports of chinook salmon in Kotzebue Sound.

Chum Salmon

The range of chum salmon extends as far south as the coastal streams of Oregon, and the rivers flowing into Tillamook Bay have consistently produced runs of chum salmon that yield a catch of one million pounds in some years. Chum salmon occur throughout the States of Washington and Alaska. They occur in considerable numbers in the tributaries of the Arctic Ocean and are the predominant species in the far north. Centers of abundance of chum salmon are the southeastern Alaska and Prince William Sound areas.

Coho Salmon

Coho salmon range as far south as northern California, where they usually enter rivers late in the fall and ascend to the headwaters of tributaries. The young characteristically stay in fresh water one year, sometimes longer. The center of abundance for coho salmon is in the streams of Oregon, Washington, and southeastern Alaska. The northern limit of range of coho salmon extends to the Nome River, and perhaps to Kotzebue Sound.

Pink Salmon

Pink salmon range as far south as the Puget Sound area, where they occur only during odd-numbered years. Their northern range extends into the Arctic Ocean, and they are regularly reported from tributaries as far north as the Kotzebue Sound area and occasionally from rivers along the northern coast of Alaska. In general, streams tributary to the Bering Sea and the Arctic Ocean produce relatively minor runs of pink salmon. Centers of abundance for pink salmon are the Kodiak, Cook Inlet, and Prince William Sound areas, but the importance of these areas is overshadowed by the pink salmon runs in southeastern Alaska.

Sockeye Salmon

Sockeye salmon, with few exceptions, are found in rivers tributary to lakes. The young live one or more years in these lakes before migrating to the sea. The southern limit of the range of sockeye salmon in the United States is the Columbia River, where they occur in the tributaries of three lakes in this system: Redfish Lake in Idaho, Wenatchee Lake in Washington, and Osoyoos Lake in British Columbia. Sockeye salmon also enter several lakes along the coast of the State of Washington. The run of sockeye salmon into Quinault Lake is of special interest, as these fish ascend the river in May and June and remain in the lake until fall before they actually move to the spawning grounds. The sockeye runs to the coastal area and Puget Sound, although of interest, are insignificant as far as commercial production is concerned.

Sockeye salmon are known to occur in Salmon Lake on Seward Peninsula, just south of Bering Strait, and are present in Kotzebue Sound. There are unconfirmed reports that sockeye salmon ascend the Noatak River (Fiscus, 1955).

The center of abundance of sockeye salmon in the United States is Bristol Bay, and to a lesser degree along the southern edge of the Alaska Peninsula and in Prince William Sound. Chignik, Karluk Lake, and Cook Inlet support good runs of sockeye salmon and thevery early run which enters the Copper River is of considerable importance. The most important area in North America, however, centers around five streams which flow into Bristol Bay. The major producer, by far, is the Kvichak River; the Naknek, Ugashik, Egegik, and Nushagak systems follow in order of importance.

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TABLE 1. Contributors of information on geographical distribution of Pacific salmon.

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TABLE 2. Geographical limits of salmon spawning areas in the United States.

Species	Southern limit	Northern limit
Chinook	San Joaquin River, California	Niukluk River (Norton Sound), Alaska
Chum	Coquille River, Oregon	Arctic Coast[1]
Pink	Puyallup River, Washington	Arctic Coast[1]
Coho	San Lorenzo River (near Monterey), California	Nome River, Alaska
Sockeye	Redfish Lake (Snake River), Idaho	Salmon Lake, Alaska

[1] These records are for United States only. Dymond (1940) reports pink and chum salmon from the Mackenzie River, Yukon Territory, Canada.

TABLE 3. Key to subareas and grid coordinates in Figures 5–110.

Subarea number	Name of subarea	Coordinates shown	Figures
1	California coast	P-31, P-32 Q-31–Q-36	5–6
2	Oregon coast	P-28–P-30 Q-26–Q-30	7–9
3	Washington coast	P-24–P-26 Q-24–Q-26	10–14
4	Oregon-Washington; Columbia River	Q-26–Q-29 R-26–R-28	15–17
5	Washington: Upper Columbia River	Q-23–Q-26 R-23–R-26	18–19
6	Oregon-Idaho: Snake River	R-26–R-30 S-26–S-30 T-28–T-30	20–21
7	Alaska: Ketchikan-Wrangell	N-16, N-17 O-16–O-18	22–26
8	Alaska: Ketchikan-Wrangell-West Coast	N-16–N-18	27–30
9	Alaska: Wrangell-Eastern-Western	N-15, N-16	31–34
10	Alaska: Wrangell	N-15, N-16	35–38
11	Alaska: Eastern-Western	M-14, M-15 N-14, N-15	39–42
12	Alaska: Eastern	N-14, N-15	43–45
13	Alaska: Icy Strait	M-13, M-14 N-13, N-14	46–48
14	Alaska: Yakutat	M-12, M-13	49–53
15	Alaska: Copper River	K-9–K-12 L-10–L-12	54–55
15*	Alaska: Prince William Sound	J-11–J-13 K-11–K-13	56–59
16A	Alaska: Cook Inlet—A	J-12, J-13	60–64
16B	Alaska: Cook Inlet—B	J-11, J-12 K-11	65–69
16C	Alaska: Cook Inlet—C	I-11–I-14 J-11, J-12	70–74
17	Alaska: Susitna River	I-10, I-11 J-9–J-11 K-10	75–79
18	Alaska: Kodiak (also Naknek and Ugashik Lakes, Alaska Peninsula)	H-14–H-16 I-14–I-16	80–83
19	Alaska: Alaska Peninsula	F-18 G-16–G-18 H-16–H-18	84–87
20	Alaska: Bristol Bay	G-13, G-14 H-12–H-14 I-12, I-13	88–92
20*	Alaska: Kuskokwim River	F-11–F-13 G-11–G-13 H-11, H-12 I-10–I-12	93–97
21	Alaska: Lower Yukon River	F-7–F-10 G-7–G-11 H-6–H-10 I-6–I-9	98–102
22	Alaska: Upper Yukon River	I-5–I-8	103–104
23	Alaska: Kotzebue Sound	F-4–F-7 G-4–G-7 H-4–H-7	105–107
23*	Alaska: Colville River	G-2–G-4 H-1–H-4 I-1–I-4 J-2–J-4	108
24	This subarea is not charted since so little information is available on spawning areas.		
25	Alaska: Aleutian Islands	A20, C-21, D-20, E-19 F-19	109–110

Continued . . .

TABLE 3. Continued.

Note: The following rivers are listed in Appendix I which are outside of the subarea divisions of this report or are in subarea 24, which is not illustrated:

Baggage River	M-3 (24)
Big Salmon River	N-11
Canning Creek	K-2-3 (24)
Dididonto River	O-14
Earn River	N-10
Glenlyon River	N-10
Harvey Creek	N-10
Hayes River	N-0-13
Jennings River	N-0-13
Kongakut River	L-3 (24)
Koshin River	O-14
Mamby Creek	L-13
McKlintock River	N-12
McMillan River	N-10
Morley River	N-0-12
Neta River	Q-17
Nisutlin River	N-12
Pelly River	M-10
Talchum River	N-11
Tay Creek	N-10
Teslin River	N-11-12
Yaktze River	L-13

TABLE 4. Key to occurrence of grid coordinates in subareas.

Grid	Subarea number
A-20	25
C-21	25
D-20	25
E-19	25
F-4	23
F-5	23
F-6	23
F-7	21, 23
F-8	21
F-9	21
F-10	21
F-11	20*
F-12	20*
F-13	20*
F-18	19
F-19	25
G-2	23*
G-3	23*
G-4	23, 23*
G-5	23
G-6	23
G-7	21, 23
G-8	21
G-9	21
G-10	21
G-11	20*, 21
G-12	20*
G-13	20, 20*
G-14	20
G-16	19
G-17	19
G-18	19
H-1	23*
H-2	23*
H-3	23*
H-4	23, 23*
H-5	23
H-6	21, 23
H-7	21, 23
H-8	21
H-9	21
H-10	21
H-11	20*
H-12	20, 20*
H-13	20
H-14	18, 20
H-15	18
H-16	18, 19
H-17	19
H-19	19
I-1	23*
I-2	23*
I-3	23*
I-4	23*

Continued . . .

TABLE 4. Continued.

Grid	Subarea number
I-5	22
I-6	21, 22
I-7	21, 22
I-8	21, 22
I-9	21
I-10	17, 20*
I-11	16C, 17, 20*
I-12	16C, 20, 20*
I-13	16C, 20
I-14	16C, 18
I-15	18
I-16	18
J-2	23*
J-3	23*
J-4	23*
J-5	22
J-6	22
J-7	22
J-8	22
J-9	17, 22
J-10	17
J-11	15*, 16B, 16C, 17
J-12	15*, 16A, 16B, 16C
J-13	15*, 16A
K-4	22
K-5	22
K-6	22
K-7	22
K-8	22
K-9	15, 22
K-10	15, 17
K-11	15*, 15, 16B
K-12	15*, 15
K-13	15*
L-4	22
L-5	22
L-6	22
L-7	22
L-8	22
L-9	22
L-10	15, 22
L-11	15
L-12	15
M-12	14
M-13	13, 14
M-14	11, 13
M-15	11
N-13	13
N-14	11, 12, 13
N-15	9, 10, 11, 12
N-16	7, 8, 9, 10
N-17	7, 8
N-18	8
O-16	7

Continued . . .

Table 4. Continued.

Grid	Subarea number
O-17	7
O-18	7
P-24	3
P-25	3
P-26	3
P-28	2
P-29	2
P-30	2
P-31	1
P-32	1
Q-23	5
Q-24	3, 5
Q-25	3, 5
Q-26	2, 3, 4, 5
Q-27	2, 4
Q-28	2, 4
Q-29	2, 4
Q-30	2
Q-31	1
Q-32	1

Continued . . .

Table 4. Continued.

Grid	Subarea number
Q-33	1
Q-34	1
Q-35	1
Q-36	1
R-23	5
R-24	5
R-25	5
R-26	4, 5, 6
R-27	4, 6
R-28	4, 6
R-29	6
R-30	6
S-26	6
S-27	6
S-28	6
S-29	6
S-30	6
T-28	6
T-29	6
T-30	6

Table 5. The numbers of streams known to be used by spawning salmon.

Species	Number of streams	Percentage of total
Chinook salmon	380	13
Chum salmon	1,270	43
Pink salmon	1,392	47
Coho salmon	771	26
Sockeye salmon	714	24

TABLE 6. Total counts of coho

	Mokelumne R.	Sacramento R. (Mill Cr.)	Eel R.	Mad R.	Umpqua R.	Rogue R.	Sandy R.	Clackamas R.
Year	Woodbridge Dam	Clough Dam	Benbow Dam	Sweasey Dam	Winchester Dam	Gold Ray Dam	Marmot Dam	North Fork Dam
1933	—	—	—	—	—	—	—	—
34	—	—	—	—	—	—	—	—
35	—	—	—	—	—	—	—	—
36	—	—	—	—	—	—	—	—
37	—	—	—	—	—	—	—	—
38	—	—	—	—	—	—	—	—
39	—	—	—	—	—	—	—	—
1940	—	—	—	—	—	—	—	—
41	—	—	—	—	—	—	—	—
42	—	—	—	—	—	4,608	—	—
43	—	—	—	—	—	3,290	—	—
44	—	—	—	—	—	3,230	—	—
45	—	—	—	—	—	1,907	—	—
46	—	—	—	—	—	3,840	—	—
47	—	—	—	—	—	5,340	—	—
48	—	—	—	—	—	1,764	—	—
49	—	—	—	—	—	9,440	—	—
1950	—	—	—	—	—	2,007	—	—
51	—	—	—	—	2,259	2,738	—	—
52	—	—	—	—	3,066	320	—	—
53	—	—	—	—	2,356	1,453	—	—
54	—	—	—	—	389	2,138	—	—
55	—	—	—	—	2,697	480	—	—
56	—	201	—	—	2,760	421	—	—
57	—	1,523	5,717	21	1,063	1,075	—	—
58	1	540	5,432	11	573	732	264	614
59	—	57	2,119	3	818	371	330	515
1960	—	—	3,184	544	346	1,851	68	1,331
61	—	—	8,479	244	531	232[1]	1,670	2,174
62	—	—	10,031	710	548	457	1,769	2,189
63	—	—	—	3,580	1,227	3,831	1,458	3,116
64	—	—	—	—	1,166	168	2,119	1,874

[1] Includes seven cohos trapped in January 1960.

salmon at dams and weirs.

Columbia River						Baker R.	Lewis R.	White R.	Cowlitz R.
Bonn. Dam	The Dalles Dam	McNary Dam	Priest Rapids Dam	Rock I. Dam	Ice Hbr. Dam	Baker Dam	Merwin Dam	Mud Mt. Dam	Mayfield Dam
—	—	—	—	182	—	2,062	—	—	—
—	—	—	—	69	—	2,786	—	—	—
—	—	—	—	10	—	19,637	—	—	—
—	—	—	—	—	—	10,082	—	—	—
—	—	—	—	58	—	3,888	—	—	—
15,185	—	—	—	78	—	14,733	—	—	—
14,383	—	—	—	13	—	7,885	19,814	—	—
11,917	—	—	—	2	—	5,343	4,508	111	—
17,911	—	—	—	29	—	5,501	8,411	12	—
12,402	—	—	—	1	—	6,721	5,128	18	—
2,547	—	—	—	22	—	4,723	8,659	1,513	—
4,207	—	—	—	186	—	9,741	8,419	708	—
790	—	—	—	166	—	14,372	6,509	968	—
3,898	—	—	—	32	—	7,431	6,088	3,809	—
11,174	—	—	—	229	—	8,255	11,829	5,023	—
4,081	—	—	—	29	—	9,778	4,750	2,013	—
1,004	—	—	—	40	—	6,774	7,238	6,742	—
10,151	—	—	—	72	—	14,209	11,197	12,510	—
5,201	—	—	—	8	—	10,529	8,912	3,823	—
7,768	—	—	—	22	—	11,542	5,614	8,588	—
13,018	—	—	—	40	—	5,638	7,237	11,976	—
4,062	—	950	—	43	—	5,151	5,435	5,780	—
3,725	—	643	—	51	—	5,513	1,718	3,133	—
6,127	—	683	—	29	—	4,473	4,139	3,425	—
4,675	6,793	2,855	—	33	—	5,264	3,178	2,099	—
3,673	2,395	1,350	—	76	—	12,854	2,232	2,092	—
2,695	2,709	1,970	—	118	—	7,245[1]	3,523	3,473	—
3,268	3,000	1,580	—	94	—	5,955	1,306	1,398	—
3,777	2,143	2,045	—	50	—	19,309	2,741	1,045	23,373
14,788	3,696	3,195	—	737	3,060	26,549	1,396	1,966	24,478
12,658	3,716	3,113	29	20	2,024	3,386	2,261	1,554	22,061
53,602	5,978	3,334	77	61	2,054	11,023	4,852	4,090	24,207

TABLE 7. Total counts of chinook

	Mokelumne R.	Sacramento R. (Mill Cr.)	Eel R.	Mad R.	Umpqua R.	Rogue R.	Sandy R.	Clackamas R.	
Year	Woodbridge Dam	Clough Dam	Benbow Dam	Sweasey Dam	Winchester Dam	Gold Ray Dam	Marmot Dam	North Fork Dam	Bonn. Dam
1933	—	—	—	—	—	—	—	—	—
34	—	—	—	—	—	—	—	—	—
35	—	—	—	—	—	—	—	—	—
36	—	—	—	—	—	—	—	—	—
37	—	—	—	—	—	—	—	—	—
38	—	—	—	—	—	—	—	—	271,799
39	—	—	—	—	—	—	—	—	286,189
1940	—	—	—	—	—	—	—	—	391,587
41	—	—	—	—	—	—	—	—	461,443
42	—	—	—	—	—	43,429	—	—	401,942
43	—	—	—	—	—	38,052	—	—	313,123
44	—	—	—	—	—	31,940	—	—	240,764
45	—	—	—	—	—	33,718	—	—	297,478
46	—	—	—	—	—	30,065	—	—	446,052
47	—	—	—	—	—	34,740	—	—	480,377
48	—	—	—	—	—	27,742	—	—	419,555
49	—	—	—	—	—	20,028	—	—	277,697
1950	—	—	—	—	—	16,767	—	—	357,375
51	—	—	—	—	2,953	21,111	—	—	331,788
52	—	—	—	—	5,273	18,488	—	—	420,879
53	—	—	—	—	4,919	33,558	—	—	332,479
54	—	—	—	—	8,190	25,785	400	—	320,947
55	—	—	—	—	8,336	16,550	5	—	359,853
56	474	1,332	1,530	129	9,498	29,952	—	—	300,917
57	2,400	3,554	3,050	495	5,243	18,770	10	—	403,286
58	6,940	3,055	1,472	489	1,459	15,716	78	460	426,419
59	2,106	1,649	473	19	3,898	14,707	304	578	345,028
1960	2,205	2,348	2,665	55	4,121	26,217	23	288	256,049
61	137	86[1]	2,046	40	5,343	33,035	37	367	285,072
62	230	801[1]	3,688	238	6,754	32,651	65	666	286,625
63	481	811[1]	2,712	232	11,205	41,527	122	616	278,560
64	—	—	—	—	9,075	38,464	660	450	344,419

[1] Fall run only.

salmon at dams and weirs.

Columbia River						Baker R.	Lewis R.	White R.	Cowlitz R.
The Dalles Dam	McNary Dam	Ice Hbr. Dam	Priest Rapids Dam	Rock I. Dam	Rocky Reach Dam	Baker Dam	Merwin Dam	Mud Mt. Dam	Mayfield Dam
—	—	—	—	5,568	—	23	—	—	—
—	—	—	—	6,482	—	31	—	—	—
—	—	—	—	16,310	—	32	—	—	—
—	—	—	—	7,396	—	11	—	—	—
—	—	—	—	5,133	—	13	—	—	—
—	—	—	—	5,803	—	—	—	—	—
—	—	—	—	11,206	—	17	1,109	—	—
—	—	—	—	9,492	—	5	8,288	—	—
—	—	—	—	2,571	—	20	976	1,089	—
—	—	—	—	6,814	—	8	396	5,432	—
—	—	—	—	11,145	—	12	710	4,603	—
—	—	—	—	3,375	—	38	984	3,756	—
—	—	—	—	5,696	—	83	1,257	2,584	—
—	—	—	—	9,992	—	19	1,228	3,843	—
—	—	—	—	11,786	—	91	1,136	1,470	—
—	—	—	—	7,095	—	4	1,088	1,841	—
—	—	—	—	12,358	—	13	796	1,378	—
—	—	—	—	8,292	—	16	1,789	1,849	—
—	—	—	—	18,794	—	26	3,226	719	—
—	—	—	—	20,114	—	7	1,690	841	—
—	—	—	—	30,908	—	7	801	931	—
—	126,555	—	—	33,261	—	3	2,718	633	—
—	108,915	—	—	25,733	—	1	1,558	630	—
—	114,342	—	—	24,910	—	4	1,946	794	—
312,678	292,696	—	—	50,745	—	24	327	374	—
301,960	226,092	—	—	32,981	—	130	232	244	—
207,461	171,490	—	—	23,334	—	236	252	261	—
196,962	176,767	—	—	26,535	—	354	1,557	528	—
201,335	154,996	—	—	33,077	—	361	762	505	5,914
187,132	152,756	94,301	—	34,155	18,545	150	838	164	6,084
180,969	154,459	61,190	45,682	34,688	10,587	532	561	447	9,960
183,842	168,107	59,573	50,035	39,951	25,312	251	2,104	658	23,953

TABLE 8. Total counts of chum salmon at dams and weirs.

	Columbia River			Southeastern Alaska		
Year	Bonneville Dam	The Dalles Dam	McNary Dam	Old Toms Creek	Katlian River	Herman Creek
1933	—	—	—	—	—	—
34	—	—	—	—	—	—
35	—	—	—	—	—	—
36	—	—	—	—	—	—
37	—	—	—	—	—	—
38	2,117	—	—	—	—	—
39	1,168	—	—	—	—	—
1940	1,729	—	—	—	—	—
41	5,269	—	—	—	—	—
42	1,865	—	—	—	—	—
43	788	—	—	—	—	—
44	954	—	—	—	—	—
45	728	—	—	—	—	—
46	1,178	—	—	—	—	—
47	199	—	—	—	—	—
48	3,636	—	—	—	—	—
49	2,028	—	—	19,000	10,000	12,000
1950	1,069	—	—	7,000	5,000	29,000
51	1,044	—	—	22,000	18,000	14,000
52	1,505	—	—	15,000	3,000	11,000
53	1,728	—	—	23,000	7,000	13,000
54	1,569	—	1	4,000	13,000	4,000
55	318	—	—	4,000	8,000	2,000
56	693	—	—	54,000	13,000	5,000
57	569	75	—	23,000	—	—
58	455	31	—	15,000	—	—
59	906	25	—	few	—	—
1960	1,026	35	—	—	—	—
61	1,097	—	—	—	—	—
62	1,013	—	—	—	—	—
63	739	23	—	—	—	—

Table 9. Total counts of pink salmon at dams and weirs.

	Baker River	Southeastern Alaska			
Year	Baker Lake	Little Port Walter	Old Toms Creek	Katlian River	Herman Creek
1933	13	—	—	—	—
34	—	—	—	—	—
35	54	—	—	—	—
36	1	—	—	—	—
37	—	—	—	—	—
38	—	—	—	—	—
39	180	—	—	—	—
1940	—	53,600	—	—	—
41	164	84,300	—	—	—
42	1	91,900	—	—	—
43	309	15,000	—	—	—
44	5	4,100	—	—	—
45	900	5,500	—	—	—
46	—	900	—	—	—
47	2,945	1,500	—	—	—
48	29	600	—	—	—
49	71	4,900	28,000	12,000	88,000
1950	5	100	17,000	2,000	54,000
51	272	4,400	52,000	14,000	91,000
52	—	—[1]	9,000	2,000	22,000
53	38	1,100	4,000	2,000	5,000
54	—	—	49,000	2,000	14,000
55	16	9,200	25,000	3,000	5,000
56	—	900	34,000	4,000	31,000
57	12	2,600	2,000	—	—
58	1	200	3,000	—	—
59	11	35,400	2,000	—	—
1960	—	162	—	—	—
61	85	28,759	—	—	—
62	1	8	—	—	—
63	171	16,757	—	—	—
64	—	2,200	—	—	—

[1] Destroyed.

TABLE 10. Total counts of sockeye salmon at dams and weirs.

Year	Columbia River								Snake River	Pr. Wm. Sound	Cook Inlet		
	Bonn. Dam	The Dalles Dam	McNary Dam	Ice Hbr. Dam	Priest Rapids Dam	Rock I. Dam	Rocky Reach Dam	Baker River Dam	Redfish Lake	Eshamy Weir	Fish Cr. (Knik Arm) Weir	Chenik Cr. Weir	English Bay Weir
1933	—	—	—	—	—	40,737	—	666	—	—	—	39,200	—
34	—	—	—	—	—	2,227	—	1,284	—	—	—	35,800	1,700
35	—	—	—	—	—	14,013	—	3,522	—	—	—	16,000	15,900
36	—	—	—	—	—	16,500	—	3,982	—	—	—	19,300	15,800
37	—	—	—	—	—	15,089	—	3,510	—	—	—	8,300	19,900
38	75,040	—	—	—	—	17,095	—	2,846	—	—	182,463	3,800	16,800
39	73,382	—	—	—	—	19,591	—	5,775	—	—	116,558	4,100	48,800
1940	148,807	—	—	—	—	27,093	—	5,166	—	—	305,982	—	30,400
41	65,741	—	—	—	—	963	—	5,937	—	—	55,077	—	26,900
42	55,464	—	—	—	—	16,340	—	6,894	—	—	—	—	—
43	39,845	—	—	—	—	17,522	—	2,435	—	—	—	—	—
44	15,072	—	—	—	—	5,035	—	2,688	—	—	—	—	—
45	9,501	—	—	—	—	7,148	—	2,737	—	—	—	—	—
46	74,376	—	—	—	—	45,030	—	4,892	—	—	57,000[1]	—	—
47	171,139	—	—	—	—	79,831	—	1,980	—	—	150,000[1]	—	—
48	131,541	—	—	—	—	84,184	—	4,610	—	—	150,000[1]	—	—
49	51,444	—	—	—	—	18,600	—	3,494	—	—	68,240	—	—
1950	77,993	—	—	—	—	50,134	—	2,416	—	30,400	29,649	—	—
51	169,428	—	—	—	—	101,826	—	3,705	—	62,700	34,704	—	—
52	184,645	—	—	—	—	114,349	—	3,401	—	42,700	92,724	—	—
53	235,215	—	—	—	—	151,747	—	3,091	—	4,600	54,345	—	—
54	130,107	—	108,181	—	—	91,234	—	2,046	1,007	1,400	23,287	—	—
55	237,748	—	173,758	—	—	165,055	—	1,076	4,361	2,900	37,445	—	—
56	156,418	—	102,145	—	—	92,443	—	1,070	1,381	46,900	42,663[2]	—	—
57	82,915	90,201	85,460	—	—	71,261	—	1,177	571	51,300	15,630	—	—
58	122,389	111,039	102,397	—	—	98,695	—	2,692	55	5,200	26,000[3]	—	—
59	86,560	86,259	83,977	—	—	72,351	—	1,911	290	800	77,416[4]	—	—
1960	59,713	59,441	55,372	—	58,201	60,341	—	1,258	75	13,815	—	—	—
61	17,111	16,689	16,388	—	19,520	19,233	11,413	450	14	47,475	—	—	—
62	28,074	27,127	29,372	37	—	29,253	13,218	3,449	39	9,490	—	—	—
63	60,319	56,931	59,744	1,118	64,883	64,768	42,236	8,241	395	—	—	—	—
64	99,855	79,042	83,931	1,276	79,071	69,411	40,590	2,242	335	—	63,128	—	—

[1] Estimated escapement—no weir installed.
[2] Estimated escapement—weir washed out.
[3] Estimated escapement—high water condition.
[4] Estimated escapement—initial year of screen count sampling method.

Continued . . .

TABLE 10. Continued.

Kodiak				Alaska Peninsula			Bristol Bay			
Alitak Bay										
Upper Station	Cannery Station	Karluk Weir	Red River Weir	Bear River Weir	Chignik Weir	Orzenoi River Weir	Kvichak River Weir	Naknek River Weir	Egegik River Weir	Ugashik River Weir
—	90,000	—	—	—	535,000	—	—	—	—	—
—	70,000	—	1,159,000	—	1,283,000	6,600	—	—	—	—
—	85,000	—	518,000	—	640,000	28,500	—	—	—	—
—	100,000	—	491,000	—	902,000	31,700	—	—	—	—
146,000	252,000	—	254,000	—	597,000	16,300	—	—	—	—
616,000	97,000	1,230,000	186,000	—	1,615,000	8,700	—	—	—	—
336,000	59,000	706,000	184,000	—	550,000	10,400	—	—	—	—
294,000	31,000	816,000	285,000	—	1,100,000	16,400	—	—	—	—
356,000	47,000	932,000	281,000	—	250,000	8,200	—	—	—	—
258,000	49,000	629,000	285,000	—	—	—	—	—	—	—
—	—	921,000	—	—	—	—	—	—	—	—
462,000	80,000	769,000	—	—	—	—	—	—	—	—
518,000	118,000	659,000	428,000	—	—	—	—	—	—	—
210,000	48,000	442,000	200,000	—	—	—	—	—	—	—
186,000	45,000	485,000	238,000	—	—	—	—	—	—	—
162,000	40,000	754,000	218,000	—	300,000	—	—	—	—	—
153,000	20,000	691,000	102,000	—	771,000	—	—	—	—	—
117,000	6,000	759,000	177,000	—	1,041,000	—	—	63,430	—	2,250,000
210,000	6,000	—	59,000	—	601,000	—	—	359,635	—	205,881
188,000	17,000	—	44,000	—	288,000	—	—	103,178	756,921	651,209
197,000	15,000	—	120,000	141,000	380,000	—	—	284,626	519,573	1,056,361
81,000	4,000	—	107,000	186,000	452,000	—	—	799,167	507,298	458,635
128,000	2,000	385,719	86,000	213,000	447,000	—	(T) 250,546	287,500	271,039	76,982
185,000	2,000	137,647	72,000	203,000	753,000	—	(T) 9,443,338	1,772,593	1,104,230	425,285
73,207	5,740	220,675	154,895	170,000	509,000	—	(T) 2,842,810	(T) 634,655	(T) 381,207	(T) 214,802
87,848	5,658	273,523	91,242	181,000	325,000	—	(T) 534,785	(T) 278,118	(T) 246,354	(T) 279,546
92,895	—	(T) 444,230	84,253	192,000	411,000	—	(T) 685,615	(T) 2,230,000	(T) 1,072,459	(T) 218,723
73,826	—	348,691	—	185,000	608,000	—	(T) 14,515,723	(T) 828,381	(T) 1,798,764	(T) 2,304,200
—	—	247,820+	—	185,000	407,000	—	(T) 3,705,849	(T) 351,078	(T) 701,538	(T) 348,639
—	—	—	—	152,000	483,000	—	(T) 2,580,572	(T) 722,062	(T) 1,027,482	(T) 255,426
—	—	—	—	152,789	532,338	—	(T) 338,760	(T) 905,358	(T) 997,602	(T) 388,254
11,562[5]	—	(T) 199,782[6]	—	279,267	301,637	—	(T) 957,120	(T) 1,349,604	(T) 849,576	(T) 472,770

[5] Escapement to July 18.

[6] Escapement to August 3.

(T) Tower counts.

TABLE 11. List of dams and fish facilities.

State, stream and dam	Type of fish facility	Vertical rise (feet)	Year fishway completed
ALASKA			
Ship Creek			
Dam Number 1	Ladder	6	1952
Dam Number 2	»	5	1954
Dam Number 3	»	4.5	1962
Dam Number 4	»	5	1965
Dam Number 5	No facility	—	—
CALIFORNIA			
Antelope Creek			
Irrigation Dam	Fishway	20	1961
Battle Creek			
Power Dam	Ladder	10	Prior 1934
Butte Creek			
Adams Dam	Fishway	8	1952
Durham Mutual Dam	»	6	1952–1960
Howard Slough Dam	»	8	1953
McGowan Brothers Dam	»	6	1952
Parrott-Phelan Dam	»	6	1952
Western Canal Dam	»	8	1950
Clear Creek			
McCormick-Saeltzer Dam	Fishway	18	—
Cosumnes River			
Granless Dam	Fishway	8	—
Deer Creek			
Stanford-Vina Dam	Fishway	10	1915
Eel River			
Benbow Dam	Fishway	15	1938
Capehorn Dam	»	40	1900–1920
Feather River			
South Butte Dam	Fishway	10	1951
Western Diversion Dam	»	8	—
Mad River			
Sweasey Dam	Ladder	64	1938
Merced River			
Cowell Dam	Fishway	6	—
Mill Creek			
Clough Dam	Fishway	20	1945
Ward Dam	»	7	1938
Irrigation Dam	»	5	—
Mokelumne River			
Woodbridge Dam	Fishway	18	1948–1955
Sacramento River			
Keswick Dam	Fishway	13	1943
Red Bank Dam	No fishway	—	—
Shasta Dam	No fishway	560[1]	—
San Lorenzo River			
Santa Cruz Water Co. Dam	Fishway	4–5	1959
Salmon River			
Sawyers Bar City Dam	Fishway	10	1948
Trinity River			
Barrier Dam	Fishway	10	—
Yuba River			
Daguerre Point Dam	Fishway	20	1951
Diversion Dam	»	—	—

Continued . . .

Table 11. Continued,

State, stream and dam	Type of fish facility	Vertical rise (feet)	Year fishway completed
Idaho			
Clearwater River			
Power Dam	Fishway	45	1939
Selway River			
Moose Creek Power Dam	Fishway	7	1962
Oregon			
Alsea River (South Fork)			
Henning Dam	Fishway (ladder)	6	1945
Big Sandy River			
Marmot Dam	Fishway (ladder)	40	1907
Calapooya River			
Diversion Dam	Fishway	5	1953
Thompson Flour Mill Dam	»	5	1956
Clackamas River			
Cazadero & North Fork Dam	Fishway (ladder)	196	1958
River Mill Dam	» »	70	1912
Deschutes River			
Pelton Dam	Ladder & Skimmer	188	1958
Round Butte	Upstream & downstream collecting & hauling	—	—
Hood River			
Powerdale Dam	Fishway (ladder)	12	1937
Hood River (East Fork)			
Dee Dam	Fishway	38	–
Lewis and Clark River			
Warrenton Dam	Fishway	15	—
Lostine River			
Lostine City Dam	Fishway	6	1963
McKenzie River			
Carmen Smith Dam	Artificial spawning	—	—
Leaburg Dam	Fishway	20	1959
Cougar Dam	Collecting & hauling	—	1960
North Santiam River			
Stayton Dam	Fishway	15.5	—
Rickreall Creek (Willamette Riv.)			
City Dam	Fishway	6	—
Rogue River			
Gold Ray Dam	Fishway (ladder)	17-23	1941
Savage Rapids Dam	Fishway	—	—
Santiam River			
Detroit Dam (N. Santiam)	Hatchery & trapping	–	1953
Lebanon Dam (S. Santiam)	3 fishways	6	1947–1960
Silver Creek (Pudding Riv.)			
Silverton City Dam	Fishway	5	—
Tualatin River (Willamette Riv.)			
Diversion Dam	Fishway	4	—
Mill Dam (Dairy Cr.)	»	—	—
Umatilla River			
Three-mile Dam	Fishway	21	1914–1964
Umpqua River			
Winchester Power Dam	Fishway	8	—
Yamhill River (North Fork)			
Carlton Dam	total block to fish	24	—
Oregon-Washington-Idaho			
Main Columbia River			

Continued . . .

TABLE 11. Continued.

State, stream and dam	Type of fish facility	Vertical rise (feet)	Year fishway Completed
Bonneville	Collection system; ladders; locks	59[1]	1938
The Dalles	Collection system; ladders; locks	88[1]	1957
John Day	Collection system; ladders	—	—
McNary	Collection system; ladders	92[1]	1953
Priest Rapids	Collection system; ladders	80.7[1]	1960
Wanapum	Collection system; ladders	81.5[1]	1963
Rock Island	Collection system; ladders	35[1]	1932
Rocky Reach	Collection system; ladders	95[1]	1961
Chief Joseph	none	175[1]	—
Grand Coulee	none; relocation hatcheries	343[1]	—
Snake River			
Ice Harbor	Fishway (ladders)	96[1]	1961
Oxbow	Collecting & hauling	117[1]	—
Brownlee	" "	277[1]	—
Swan Falls	Fishway	—	—
WASHINGTON			
Cowlitz River			
Mayfield Dam	Collecting & hauling	185	1962
Deschutes River			
Capitol Lake Dam	Collecting & hauling	—	1949
Entiat River			
Irrigation Dam	Collecting & hauling	4	1947
Methow River (*Columbia River*)			
Irrigation Dam	Fishway	4	1944
Nisqually River			
Water Supply Dam	Fishway	—	—
Okanogan River			
Zosel Dam	Fishway	4	1947
Pilchuck River			
Water Supply Dam	Fishway	6	1949
Skookumchuck River			
Mill Dam	Fishway	—	1935
Touchet River (*Walla Walla Riv.*)			
Eastside-Westside Dam	Fishway	3	1962
Tucannon River (*Snake River*)			
Diversion Dam	Fishway	5	1964
Starbuck Dam	"	3	1964
Unnamed Slough (*Chehalis River*)			
Dam	Fishway	—	1936
Walla Walla River (*Columbia Riv.*)			
Burlingame Dam	Fishway	5	1949
Wenatchee River (*Columbia Riv.*)			
Dryden Dam	Fishway	4	1948
Tumwater Dam	"	—	1940
White River (*Puyallup River*)			
Water Supply Dam	Fishway	5	1949
Mud Mountain Dam	"	—	—
Yakima River			
Easton Dam	Fishway	—	—
Horn Rapids Dam	"	4	1930
Prosser Dam	"	14	1930–1956
Sunnyside Dam	"	7	1929
Roza Dam	"	34	1938
Wapato Dam	"	11	1917

[1] Gross head of dam.

TABLE 12. Fishways at natural obstructions.

State and stream	Year Completed	Extent of area opened to salmon
ALASKA		
Bakewell Creek (Ketchikan)	1957	740 acre lake plus 14 miles of stream
Billies Hole (Prince William Sound)	1963	2½ miles
Falls Creek (Petersburg)	1951	8 ½ miles
Fritz Creek (Homer)	1961	8 miles
Gretchen Creek (Afognak I.)	1952–64	53 acre lake, 1 3/4 miles of stream
Ketchikan Creek	1957	—
Laura Creek (Afognak I.)	1952–1963	616 acre lake plus ½ mile of stream
Naha Creek	1949	—
Shrode Creek (Prince William Sound)	1962	500 acre lake plus tributaries 1 3/4 miles
Frazer Lake (Kodiak I.)	1963	6,000 acre lake plus 28 miles of tributary stream
CALIFORNIA		
Big Chico Creek	1958	13 miles
Deer Creek	1942–1954	17 ½ miles
Hayfork River	1964	18 miles
IDAHO		
Clearwater River, S. Fork	1963	70 miles
Lochsa River	1962	—
Salmon River (Middle Fork)	1961	100 miles
Selway River	1962	70 miles
OREGON		
Clatskanie River	1953	16 miles
Coquille River, N. Fork	1955	12 miles
Deschutes River & tributaries	1920–1948	150 miles
Eagle Creek (Clackamas River)	1957	27 miles
Fall Creek (Alsea River)	1948	12 miles
Farnam Creek (Siuslaw River)	1962	95+ miles
Hawley Creek (Siuslaw River)	1962	—
Hood River, West Fork	1956	—
Illinois River (Rogue River)	1961	58 miles
Klaskanine River (Columbia River)	1963	7 miles
Little Nestucca River	1948–1950	—
Little North Fork (Santiam River)	1958	14 miles
Middle Creek (Coquille River)	1963	10 miles
Millicoma River (Coos River)	1956	30 miles
Minam River (Grande Ronde River)	1964	15 miles
Nehalem River	1952	130 miles
Nehalem River, N. Fork	1958	25+ miles
Scappoose Creek (Columbia River)	1951–1957	15+ miles
Siletz River	1953	—
Smith River	1949–1964	150+ miles
Steamboat Creek (Umpqua River)	(1959)	24 miles
Steel Creek (Coquille River)	1961–1963	—
Umpqua River	1955	25 miles
Willamette River	1920	2,400+ miles
WASHINGTON		
Abernathy Creek (Columbia River)	1954	14 miles
Chambers Creek (Puget Sound)	1951–1954	3 miles
Coweman River (Cowlitz River)	1955	9 miles
Deschutes River (Puget Sound)	1953–1954	25 miles
Duckabush River (Hood Canal)	1952	7 miles
Elokomin River (Columbia River)	1957	8 miles
Fall River (Willapa Bay)	1964	7 miles
Grays River, E. Fork (Columbia Riv.)	1956	3 miles
Green River (Toutle River)	1958	13 miles

Continued . . .

TABLE 12. Continued.

State and stream	Year Completed	Extent of area opened to salmon
Hoko River (Strait of Juan de Fuca)	1952	20 miles
Kalama River (Columbia River)	1957	30 miles
Klickitat River (Columbia River)	1954–1963	25+ miles
Olequa Creek (Cowlitz River)	1952–1953	1½ miles
Skookumchuck River (Chehalis River)	1950	12 miles
Skykomish River	1958	30 miles
Stillaguamish River, S. Fork	1954–1957	25+ miles
Washougal River (Columbia River)	1954–1956	1+ miles
Wind River (Columbia River)	1954–1955	20+ miles

Table 13—overleaf

TABLE 13. Salmon hatcheries operated on the United States Pacific Coast, 1872–1962—Alaska, California, Idaho.

	ALASKA													CALIFORNIA																											IDAHO	
Year	Afognak	Callbreath	Cordova	Fire Lake	Fortmann	Hetta	Juneau	Karluk	Ketchikan	Klawak	Quadra	Seward	Yes Bay	Baird-McCloud	Battle Creek	Bear Valley	Big Creek	Brookdale	Burney Creek	Cold Creek	Eel River—	Cedar Creek	Fort Seward	Price Creek	Darrah Springs	Feather River	Forest Home	Hat Creek	Humbolt State College	Hornbrook	Klamath—Fall Creek	Lake Alamandor	Mad River	Mill Creek	Moccasin Creek	Mt. Shasta	Nimbus	Prairie Creek	Sacramento Exper. Sta.	Trinity—Fort Gaston	Salmon River	Year
1872	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1872
73	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	73
74	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	74
75	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	75
76	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	76
77	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	77
78	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	78
79	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	79
1880	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1880
81	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	81
82	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	82
83	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	83
84	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	84
85	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	85
86	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	I	—	—	—	—	—	—	—	—	—	—	—	—	—	86
87	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	C	—	—	—	—	—	—	—	X	—	—	—	—	—	87
88	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	88
89	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	89
1890	—	—	—	—	—	—	—	—	—	—	—	—		U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	1890
91	—	—	—	—	—	—	—		—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	91
92	—	P	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	92
93	—	P	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	X	—	—	—	U	—	93
94	—	P	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	X	—	—	—	U	—	94
95	—	P	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	X	—	—	—	U	—	95
96	—	P	—	—	—	—	—	P	—	—	—	—	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	C	—	—	X	—	—	—	U	—	96
97	—	P	—	—	—	P	—	P	—	P	P	—	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	X	—	—	—	I	—	97
98	—	P	—	—	P	P	—	P	—	P	P	—	—	U	U	U	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	C	—	—	X	—	—	—	C	—	98
99	—	P	—	—	P	P	—	P	—	P	P	—	—	U	U	—	—	—	—	—	—	—	—	D	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	99
1900	—	P	—	—	P	P	—	P	—	P	P	—	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	1900
01	—	P	—	—	P	P	—	P	—	P	P	—	—	U	U	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	U	—	X	—	—	—	—	—	01
02	—	P	—	—	P	P	—	P	—	P	P	—	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	X	—	—	—	—	—	02
03	—	P	—	—	P	P	—	P	—	P	P	—	—	U	U	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	U	—	X	—	—	—	—	—	03
04	—	P	—	—	P	P	—	P	—	P	P	—	U	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	X	—	—	—	—	—	04
05	—	P	—	P	P	P	—	P	—	P	P	—	U	U	U	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	U	—	X	—	—	—	—	—	05
06	—	P	—	P	P	P	—	P	—	P	P	—	U	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	X	—	—	—	—	—	06
07	U	—	—	P	P	P	—	P	—	P	P	—	U	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	X	—	—	—	E	—	07
08	U	—	—	P	P	P	—	P	—	P	P	—	U	U	U	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	U	—	X	—	—	—	—	—	08
09	U	—	—	P	P	P	—	P	—	P	P	—	U	U	U	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	U	—	X	—	—	—	—	—	09

1910	U	—	—	P	P	P	—	P	—	P	P	—	U	U	U	—	—	—	—	—	—	—	—	X	—	—	—	—	—	U	—	—	—	U	—	X	—	—	X	—	—	1910
11	U	—	—	P	P	P	—	P	—	P	P	—	U	U	U	—	—	X	—	—	—	—	—	D	—	—	—	—	—	U	—	—	—	U	—	X	—	—	X	—	—	11
12	U	—	—	P	P	P	—	P	—	P	P	—	U	U	U	—	—	X	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	U	—	X	—	—	C	—	—	12
13	U	—	—	P	P	P	—	P	—	P	P	—	U	U	U	—	—	—	—	—	—	—	—	X	—	—	—	—	—	U	—	—	—	U	—	X	—	—	—	—	—	13
14	U	—	—	P	P	P	—	P	—	P	P	—	U	I	U	—	—	—	—	—	—	—	—	X	—	—	—	—	—	U	—	—	—	U	—	X	—	—	—	—	—	14
15	U	—	—	P	P	P	—	P	—	P	P	—	U	I	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	R	—	—	—	U	—	X	—	—	—	—	—	15
16	U	—	—	P	P	P	—	—	—	P	P	—	U	I	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	U	—	X	—	—	—	—	—	16
17	U	—	—	P	P	—	—	—	—	P	P	—	U	I	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	X	—	—	—	—	—	17
18	U	—	—	P	—	—	P	—	—	—	P	—	U	I	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	X	—	—	—	—	—	18
19	U	—	—	P	—	—	P	—	—	—	P	—	U	I	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	X	—	—	—	—	—	19
1920	U	—	—	P	—	—	P	—	—	—	P	—	U	I	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	X	—	—	—	—	U	1920
21	U	—	P	P	—	—	P	—	—	—	P	—	—	I	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	X	—	—	—	—	U	21
22	U	—	P	P	—	—	P	—	—	—	P	—	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	X	—	—	—	—	U	22
23	U	—	P	P	—	—	P	—	—	—	P	P	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	X	—	—	—	—	U	23
24	U	—	P	P	—	—	P	—	—	—	P	P	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	X	—	—	—	—	U	24
25	U	—	P	P	—	—	P	—	—	—	P	P	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	X	—	—	—	—	U	25
26	U	—	P	P	—	—	P	—	—	—	P	—	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	X	—	—	—	—	U	26
27	U	—	P	P	—	—	—	—	—	—	P	—	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	U	—	X	—	—	—	—	U	27
28	U	—	—	P	—	—	—	—	—	—	P	—	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	X	—	—	X	—	U	28
29	U	—	—	P	—	—	—	—	—	—	P	—	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	X	—	—	X	—	U	29
1930	U	—	—	P	—	—	—	—	—	—	P	—	—	U	U	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	X	—	U	1930
31	U	—	—	P	—	—	—	—	—	—	P	—	—	I	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	X	—	—	X	—	U	31
32	U	—	—	—	—	—	—	—	—	—	P	—	—	I	U	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	X	—	—	X	—	U	32
33	U	—	—	—	—	—	—	—	—	—	P	—	—	I	U	—	—	X	X	—	—	—	—	—	—	X	—	—	—	—	X	—	—	U	—	—	—	—	X	—	U	33
34	—	—	—	—	—	—	—	—	—	—	—	—	—	I	U	—	—	X	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	U	—	X	—	—	X	—	U	34
35	—	—	—	—	—	—	—	—	—	—	—	—	—	I	U	—	—	X	—	—	—	—	—	X	—	X	—	—	—	—	X	—	—	U	—	X	—	—	X	—	U	35
36	—	—	—	—	—	—	—	—	—	—	—	—	—	I	U	X	—	X	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	U	—	X	—	—	X	—	—	36
37	—	—	—	—	—	—	—	—	—	—	—	—	—	C	U	X	—	X	—	X	—	—	—	—	—	X	—	—	—	—	X	—	—	U	—	X	—	—	X	—	C	37
38	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	U	—	X	—	—	X	—	—	38
39	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	U	—	X	—	—	X	—	—	39
1940	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	U	—	X	—	—	X	—	—	1940
41	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	X	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	U	—	—	—	—	X	—	—	41
42	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	U	—	—	—	—	X	—	—	42
43	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	43
44	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	44
45	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	45
46	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	46
47	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	47
48	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	48
49	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	49
1950	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	1950
51	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	51
52	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	52
53	—	—	—	X	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	53
54	—	—	—	X	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	X	X	—	—	X	—	—	54
55	X	—	—	X	—	—	—	—	X	—	—	—	—	—	U	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	X	X	X	—	X	—	—	55
56	X	—	—	X	—	—	—	—	X	—	—	—	—	—	U	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	X	X	X	—	X	—	—	56
57	X	—	—	X	—	—	—	—	X	—	—	—	—	—	U	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	X	X	X	—	X	—	—	57
58	X	—	—	X	—	—	—	—	X	—	—	—	—	—	U	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	X	X	X	—	X	—	—	58
59	X	—	—	X	—	—	—	—	X	—	—	—	—	—	U	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	X	X	X	—	X	—	—	59
1960	X	—	—	X	—	—	—	—	X	—	—	—	—	—	U	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	X	X	X	—	X	—	—	1960
61	X	—	—	X	—	—	—	—	X	—	—	—	—	—	U	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	X	X	X	—	X	—	—	61
62	X	—	—	X	—	—	—	—	X	—	—	—	—	—	U	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	X	X	X	—	X	—	—	62

C=Closed by flood; D=destroyed by flood, etc.; E=eyeing station; I=insufficient spawners; P=privately operated; R=relocated; U=operated by U.S. Govt.; X=operated by state

TABLE 13. Continued—Oregon (part).

Year	OREGON																																												Year
	Alsea	Applegate	Big Creek	Bonneville	Breitenbush	Calapooya	Cascade	Cedar Creek	Clackamas-Cazedero	Clackamas-Lower	Clackamas	Clackamas-Upper	Coos Bay	Coquille River	Deschutes	Eagle Creek	Gates Creek	Grand Ronde-Wallowa	Imnaha	Klaskanine	Lewis Clarke Expos.	McKenzie	Mill Creek-Scottsberg	Metolius	Molalla	Nehalem	Nestucca	North Lake	Ontario-Swan Falls	Oxbow-Herman Creek	Rogue River-Butte Falls	Rogue River-Ellensburg	Rogue River-Elk Creek	Salmon River-Sandy	Sandy-Oswego	Santiam-Marion Springs	Santiam-South	Spencer Creek	Siletz	Siuslaw	Tahkenite	Tanner Creek	Ten Mile Creek	Tillasqua	
1872	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1872
73	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	73
74	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	74
75	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	75
76	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	76
77	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	77
78	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	78
79	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	79
1880	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	1880
81	—	—	—	—	—	—	—	—	—	—	D	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	81
82	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	82
83	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	83
84	—	—	—	—	—	—	—	—	—	—	I	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	84
85	—	—	—	—	—	—	—	—	—	—	I	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	85
86	—	—	—	—	—	—	—	—	—	—	I	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	86
87	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	87
88	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	88
89	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	89
1890	—	—	—	—	—	—	—	—	—	—	U	E	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	1890
91	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	91
92	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	U	—	—	—	—	—	—	—	—	—	—	92
93	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	X	—	—	—	—	93
94	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	—	X	—	—	—	—	94
95	—	—	—	—	—	—	—	—	—	—	X	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	E	—	—	—	—	—	I	—	—	—	—	95
96	—	—	—	—	—	—	—	—	—	—	U	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	U	—	E	—	—	—	—	—	U	—	—	—	—	96
97	—	—	—	—	—	—	—	—	—	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	U	U	—	—	—	—	—	U	—	—	—	—	97
98	—	—	—	—	—	—	—	—	—	—	U	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	U	U	—	—	—	—	—	—	X	—	—	—	—	98
99	—	—	—	—	—	—	—	—	—	—	U	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	U	U	D	—	—	—	—	—	X	—	—	—	—	99
1900	—	—	—	—	—	—	—	—	—	—	U	R	X	—	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	U	X	—	—	—	—	—	X	—	U	—	—	1900
01	—	—	—	—	—	—	—	—	—	X	R	E	X	X	—	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	U	X	—	—	—	—	—	X	—	U	—	—	01
02	X	—	—	—	—	—	—	—	—	X	U	X	X	C	—	U	—	X	—	—	—	X	—	—	—	—	—	—	X	—	—	U	U	X	—	—	—	—	—	X	—	U	—	—	02
03	X	—	—	—	—	—	—	—	—	X	U	X	X	X	—	U	—	X	—	—	—	—	—	—	—	—	—	—	X	—	—	U	U	X	—	—	—	—	—	X	—	U	—	—	03
04	—	—	—	—	—	—	—	—	—	U	U	U	X	—	—	U	—	X	—	—	—	—	—	—	—	—	—	—	X	—	—	U	U	X	—	—	—	—	—	X	—	U	—	—	04
05	R	—	—	—	—	—	—	—	—	—	U	U	X	E	—	—	—	R	—	—	X	X	—	—	—	—	—	—	X	—	—	U	U	X	—	—	—	—	—	X	—	—	—	—	05
06	X	—	—	—	X	—	—	—	X	—	U	U	X	E	—	—	—	X	—	—	—	X	—	—	—	—	—	—	X	—	—	U	U	X	—	—	—	—	—	X	—	—	—	—	06
07	—	—	—	—	D	—	—	—	X	—	U	U	X	E	—	U	—	X	—	—	—	X	—	—	—	—	—	—	X	—	—	U	U	X	—	X	—	—	—	X	—	U	—	—	07
08	X	—	—	—	—	—	—	—	X	—	U	—	X	E	—	U	—	X	—	—	—	X	—	—	—	—	—	—	X	—	—	C	U	X	—	—	—	—	—	X	—	U	—	—	08
09	—	—	—	—	D	—	—	—	U	—	U	—	X	X	—	U	—	X	—	—	—	X	—	—	—	—	—	—	D	—	—	—	U	X	—	—	—	—	—	X	—	U	—	—	09

1910	—	—	—	X	—	—	—	—	—	—	U	—	X	X	—	—	—	X	—	—		X	—	—	—	—	—	—	—	—	—	—	U	X	—	D	—	—	—	X	—	—	—	—	1910
11	E	—	—	X	—	—	—	—	—	—	U	—	X	X	—	—	—	X	—	X	—	X	—	—	—	—	—	—	C	—	—	—	U	I	—	E	—	—	—	X	—	—	—	—	11
12	E	U	—	X	—	—	—	—	—	—	U	—	X	X	—	U	—	X	—	X	—	X	—	—	—	—	X	—	—	—	—	X	U	X	—	D	—	—	—	X	—	U	—	—	12
13	E	U	—	X	—	—	—	—	R	—	U	—	X	X	—	U	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	U	C	—	—	—	—	—	X	—	U	—	—	13
14	—	U	—	X	—	—	—	—	—	—	U	—	X	X	—	—	—	—	—	X	—	X	—	—	—	—	—		—	—	—	—	U	—	—	—	—	—	—	X	—	U	—	—	14
15	R	U	—	X	—	—	—	—	—	—	R	—	X	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—	—	X	—	U	—	—	15
16	X	U	—	X	—	—	—	—	—	—	U	U	X	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—	U	—	—	X	—	X	—	X	—	U	—	—	16
17	X	U	—	X	—	—	—	—	—	—	U	U	X	X	—	U	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—	U	—	—	X	—	—	—	X	—	U	—	—	17
18	X	U	—	X	—	—	—	—	—	—	U	U	X	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—	U	—	—	X	—	—	—	X	—	U	—	—	18
19	X	U	—	X	—	—	—	—	—	—	U	U	X	X	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—	U	—	—	X	X	—	—	X	—	—	—	—	19
1920	X	U	—	X	—	—	—	—	—	—	U	U	X	—	X	U	—	X	—	X	—	X	—	—	—	X	—	—	—	X	—	—	U	—	—	X	X	—	—	X	—	—	—	—	1920
21	X	U	—	X	—	—	—	—	—	—	U	U	X	X	X	—	—	R	—	X	—	X	—	—	—	X	—	—	—	X	—	—	U	U	—	X	X	—	—	X	—	—	—	—	21
22	X	U	—	X	—	—	—	—	—	—	U	U	X	—	X	—	—	X	—	X	—	X	—	—	—	X	—	—	—	X	—	—	U	U	—	X	X	—	—	X	—	—	—	—	22
23	X	U	—	X	—	—	—	—	—	—	U	U	X	—	X	—	—	X	—	X	—	X	—	—	—	X	—	—	—	X	—	—	U	U	—	X	X	—	—	X	—	—	—	—	23
24	X	U	—	X	—	—	—	—	—	—	U	U	X	X	X	—	X	X	X	X	—	X	—	—	—	X	X	—	—	X	—	—	U	—	—	X	X	—	—	X	—	—	—	—	24
25	X	U	—	X	—	—	—	—	—	—	U	U	X	—	X	—	X	X	X	X	—	X	—	—	—	X	X	—	—	X	—	—	U	X	—	X	X	—	—	X	—	—	—	—	25
26	X	U	—	X	X	—	—	—	—	U	—	U	X	X	X	—	—	X	—	X	—	X	X	—	—	—	—	—	—	X	—	—	U	—	—	X	X	—	—	X	—	—	—	—	26
27	X	U	—	X	—	—	—	—	—	U	—	—	X	—	X	—	—	X	—	X	—	X	X	—	X	X	X	—	—	X	—	—	U	—	—	X	X	—	—	X	—	—	—	—	27
28	X	U	—	X	X	—	—	—	—	I	—	U	X	—	X	—	—	X	—	X	—	X	X	—	X	X	X	—	—	X	—	—	U	—	—	X	X	—	—	X	—	—	—	—	28
29	X	U	—	X	—	—	—	—	—	C	—	U	X	—	X	—	—	X	—	X	—	X	X	—	X	X	X	—	—	X	—	—	U	—	—	X	X	—	—	X	—	—	—	X	29
1930	X	U	—	X	—	—	—	—	—	U	—	U	X	—	X	—	—	X	—	X	—	X	—	—	—	X	X	—	—	X	—	—	U	—	—	X	X	—	—	X	—	—	—	X	1930
31	X	U	—	X	—	—	—	—	—	U	—	—	X	E	X	—	—	X	—	X	—	X	—	—	—	X	X	—	—	X	—	—	E	—	—	X	X	—	—	X	—	—	—	X	31
32	X	U	—	X	—	—	—	—	—	U	—	—	X	E	X	—	—	X	—	X	—	X	—	—	—	X	X	—	—	X	—	—	E	—	—	X	X	—	—	X	—	—	—	X	32
33	X	—	—	X	—	—	—	—	—	U	—	—	X	E	X	—	—	X	—	X	—	X	—	—	—	X	X	—	—	X	U	—	E	—	—	X	X	—	—	X	—	—	—	X	33
34	X	—	—	X	—	—	—	—	—	U	—	—	X	E	X	—	—	X	—	X	—	X	—	—	—	X	X	—	—	X	U	—	E	—	—	X	X	—	—	—	—	—	X	X	34
35	X	—	—	X	—	—	—	—	—	U	—	—	X	—	X	—	—	X	—	X	—	X	—	—	—	R	—	—	—	X	U	—	—	—	—	X	X	—	—	—	—	—	X	X	35
36	X	—	—	X	—	—	—	X	—	U	—	—	X	—	X	—	—	X	—	X	—	X	—	—	—	X	—	—	—	X	U	—	C	—	—	X	X	—	—	—	—	—	X	X	36
37	X	—	—	X	—	—	—	X	—	U	—	—	X	I	X	—	—	X	—	X	—	X	—	—	—	X	—	—	—	X	U	—	—	—		X	X	—	—		—	—	X	X	37
38	X	—	—	X	—	—	—	X	—	U	—	—	X	X	—	—	—	X	—	X	—	X	X	—	—	X	—	X	—	X	U	—	—	—	—	X	X	—	X	—	X	—	X	X	38
39	X	—	—	X	—	—	—	X	—	U	—	—	X	X	X	—	—	C	—	X	—	X	X	—	—	X	—	X	—	X	X	—	X	—	X	X	X	—	X	X	X	—	X	X	39
1940	X	—	—	X	—	—	—	X	—	—	—	—	X	X	X	—	—	—	—	X	—	X	X	—	—	X		X	—	X	X	—	X	—	X	X	X	—	X	X	X	—	X	X	1940
41	X	—	—	X	—	—	—	X	—	—	—	—	X	X	X	U	—	—	—	X	—	X	X	—	—	X	—	—	—	X	X	—	X	—	X	X	X	—	X	X	—	—	X	X	41
42	X	—	—	X	—	—	—	X	—	—	—	—	X	X	X	U	—		—	X	—	X	X	—	—	X	—	—	—	X	X	—	C	—	X	X	X	—	X	X	—	—	X	X	42
43	X	—	—	X	—	—	—	X	—	—	—	—	X	X	X	U	—	—	—	X	—	X	X	—	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	X	—	—	X	X	43
44	X	—	—	X	—	—	—	X	—	—	—	—	X	X	X	U	—	—	—	X	—	X	X	—	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	X	—	—	X	X	44
45	X	—	—	X	—	—	—	X	—	—	—	—	X	X	X	U	—	—	—	X	—	X	—	—	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	X	—	—	X	X	45
46	X	—	—	X	—	—	—	X		—	—	—	X	X	X	U	—	—	—	X	—	X	—	—	—	X	—		—	X	X	—	—	—	X	X	X	—	X	X	—	—	X	X	46
47	X	—	—	X	—	—	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	—	—	X	—		—	X	X	—	—	—	X	X	X	—	X	X	—	—	—	X	47
48	X	—	—	X	—	—	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X		X	—		—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	X	48
49	X	—	—	X	—	—	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	X	49
1950	X	—	—	X	—	—	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	X	1950
51	X	—	—	X	—	—	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	X	51
52	X	—	—	X	—	—	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	X	52
53	X	—	—	X	—	—	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	X	53
54	X	—	—	X	—	—	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	X	54
55	X	—	X	X	—	—	X	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	X	55
56	X	—	X	X	—	—	X	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	X	56
57	X	—	X	X	—	—	X	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—		X	57
58	X	—	X	X	—	—	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	X	58
59	X	—	X	X	—	X	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X		X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	—	59
1960	X	—	X	X	—	X	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	—	1960
61	X	—	X	X	—	X	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	—	—	61
62	X	—	X	X	—	X	—	X	—	—	—	—	X	—	X	U	—	—	—	X	—	X	—	X	—	X	—	—	—	X	X	—	—	—	X	X	X	—	X	—	—	—	E	—	62

C=closed by flood; D=destroyed by flood, etc.; E=eyeing station; I=insufficient spawners; P=privately operated; R=relocated; U=operated by U.S. Govt.; X=operated by state

TABLE 13. Continued—Oregon (concluded), Washington (part).

	OREGON								WASHINGTON																																			
Year	Tillamook	Trask-Gold Creek	Troy	Umpqua	Warrendale	Willamette-Oak Ridge	Wilson River	Yaquina	Baker Lake	Birdsview	Bowmans Bay	Brunnion-Walcott	Carson	Chambers Cr.	Chehalis	Chehalis-Dryad	Chinook	Colville	Cowlitz	Crescent Lake	Darrington	Day Creek	Deschutes	Duckabush	Dungeness	Elokomin	Elwha	Entiat	George Adams	Grays River	Green River	Hood Canal	Humptulips	Illalot Cr.	Illinois Rv.	Issaquah	Kalama Falls	Kalama No. 2	Kittitas	Klickitat	Lewis River	Little Spokane	Methow-Pateros	Year
1872	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1872
73	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	73
74	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	74
75	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	75
76	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	76
77	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	77
78	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	78
79	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	79
1880	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1880
81	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	81
82	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	82
83	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	83
84	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	84
85	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	85
86	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	86
87	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	87
88	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	88
89	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	89
1890	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1890
91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	91
92	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	92
93	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	93
94	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	94
95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	95
96	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	96
97	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	97
98	—	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	98
99	—	—	—	—	—	—	—	—	U	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	R	—	—	—	—	I	X	99
1900	—	—	—	X	—	—	—	—	U	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	I	X	1900
01	—	—	—	X	—	—	—	X	U	—	—	—	—	—	X	—	X	X	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	I	X	01
02	—	—	—	X	—	—	—	X	U	—	—	—	—	—	X	—	X	C	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	02
03	—	—	—	X	—	—	—	X	U	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	03
04	—	—	—	X	—	—	—	X	U	U	—	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	04
05	—	—	—	X	—	U	—	X	U	U	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	05
06	—	—	—	X	—	U	—	X	U	U	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	06
07	X	—	—	X	—	U	—	X	U	U	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	07
08	X	—	—	X	—	U	—	X	U	U	—	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	08
09	—	—	—	X	—	—	—	X	—	U	—	—	—	—	R	—	X	—	—	—	U	—	—	—	D	—	—	—	—	—	X	—	—	—	U	—	X	—	—	—	—	—	X	09

1910	X	—	—	X	—	—	—	X	U	U	—	—	—	—	X	—	X	—	—	—	U	—	—	—	X	—	—	—	—	—	X	—	—	U	—	—	X	—	—	—	—	—	X	1910
11	X	—	—	X	—	E	—	X	U	U	—	—	—	—	X	—	X	—	—	—	U	—	—	—	X	—	—	—	—	—	X	—	—	U	—	—	X	—	—	—	—	—	X	11
12	X	—	—	X	—	—	X	X	U	U	—	—	—	—	X	—	X	—	—	—	U	—	—	U	X	—	—	—	—	—	X	—	—	U	—	—	X	—	—	—	X	—	X	12
13	X	—	—	—	—	I	X	X	U	U	—	—	—	—	X	—	X	—	—	—	U	U	—	U	D	—	X	—	—	—	X	—	—	U	U	—	X	—	—	—	X	—	X	13
14	X	—	—	—	—	X	—	—	D	U	—	U	—	—	X	—	X	—	—	—	U	U	—	U	X	—	X	—	—	—	X	—	X	U	U	—	X	—	—	—	X	—	X	14
15	X	—	—	—	—	X	—	—	U	U	—	U	—	—	X	—	X	—	—	—	U	U	—	U	X	—	X	—	—	—	X	—	X	U	—	—	X	—	—	—	X	—	R	15
16	X	X	—	X	—	X	—	—	U	U	—	U	—	X	X	—	X	—	—	—	U	U	—	U	X	—	X	—	—	—	X	—	X	U	—	—	X	—	—	—	X	—	X	16
17	X	X	—	—	—	X	—	—	U	U	—	U	—	X	X	X	X	—	—	—	U	U	—	U	X	—	X	—	—	—	X	—	X	U	—	—	X	—	—	—	X	—	X	17
18	X	X	—	—	—	X	—	—	U	U	—	U	—	X	X	X	X	—	—	—	U	—	—	U	X	—	X	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	X	18
19	X	X	—	—	—	X	—	—	D	U	—	U	—	X	X	X	X	—	—	—	U	—	—	U	X	—	X	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	X	19
1920	X	X	—	X	—	X	—	—	U	U	—	U	—	X	X	X	X	—	—	—	—	—	—	U	X	—	X	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	X	1920
21	X	X	—	X	—	X	—	—	U	U	—	U	—	X	X	X	X	—	—	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	X	21
22	X	X	—	X	—	X	—	—	U	U	—	U	—	X	X	X	X	—	—	—	—	—	—	U	X	—	C	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	X	22
23	X	X	—	X	—	X	—	—	U	U	—	U	—	X	X	X	X	—	—	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	X	—	X	—	X	23
24	—	X	X	X	—	X	—	R	D	U	—	—	—	X	X	X	X	—	—	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	X	—	X	—	X	24
25	—	X	—	X	—	X	—	X	U	U	—	—	—	X	X	X	X	—	—	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	X	—	X	—	X	25
26	—	X	—	X	—	X	—	X	U	U	—	—	—	X	X	X	X	—	X	—	—	—	—	U	X	—	—	—	—	—	X	—	X	U	—	—	X	—	X	—	X	—	X	26
27	—	X	—	X	—	X	—	X	U	U	—	U	—	X	X	X	X	—	X	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	X	27
28	—	X	—	X	—	X	—	—	U	U	—	U	—	X	X	X	X	—	X	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	C	—	X	28
29	—	X	—	X	—	X	—	—	U	U	—	U	—	X	X	X	X	—	X	U	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	X	—	—	—	X	29
1930	—	X	—	X	—	X	—	X	U	U	—	U	—	X	X	X	X	—	X	U	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	X	—	X	—	X	1930
31	—	X	—	X	—	X	—	—	—	U	—	—	—	X	X	—	X	—	X	U	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—	31
32	—	X	—	X	—	X	—	—	U	U	—	—	—	X	X	—	X	—	X	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	R	—	—	32
33	—	X	—	X	—	X	—	—	U	U	—	—	—	I	X	—	X	—	X	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—	33
34	—	X	—	X	—	X	—	—	U	U	—	—	—	—	X	—	X	—	X	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—	34
35	—	X	—	X	—	X	—	—	—	U	—	—	—	—	X	—	X	—	X	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—	35
36	—	X	—	X	—	X	—	—	D	U	—	—	—	—	X	—	—	—	X	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—	36
37	—	X	—	X	—	X	—	X	—	U	—	—	U	—	X	—	—	—	X	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	X	X	—	—	—	X	—	—	37
38	—	X	—	X	—	X	—	X	—	U	—	—	U	—	X	—	—	—	X	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	X	X	—	—	—	X	—	—	38
39	—	X	—	X	—	X	—	X	—	U	—	U	U	—	C	—	—	—	X	—	—	—	—	U	X	—	—	—	—	—	X	—	X	—	—	X	X	—	—	—	X	—	—	39
1940	—	X	—	X	—	X	—	X	—	U	—	—	U	—	—	—	—	—	X	—	—	—	—	U	X	—	—	U	—	—	X	—	X	—	—	X	X	—	—	—	X	—	—	1940
41	—	X	—	X	—	X	—	X	—	U	—	—	U	—	—	—	—	—	X	—	—	—	—	U	X	—	—	U	—	—	X	—	X	—	—	X	X	—	—	—	X	—	—	41
42	—	X	—	X	—	X	—	X	—	U	—	—	U	—	—	—	—	—	X	—	—	—	—	—	X	—	—	U	—	—	X	—	X	—	—	X	X	—	—	—	X	—	—	42
43	—	X	—	X	—	X	—	X	—		—	—	U	—	—	—	—	—	X	—	—	—	—	—	X	—	—	U	—	—	X	—	X	—	—	X	X	—	—	—	X	—	—	43
44	—	X	—	X	—	X	—	X	—	—	—	—	U	—	—	—	—	—	X	—	—	—	—	—	X	—	—	U	—	—	X	—	X	—	—	X	X	—	—	—	X	—	—	44
45	—	X	—	X	—	X	—	X	—	—	—	—	U	—	—	—	—	—	X	—	—	—	—	—	X	—	—	U	—	—	X	—	X	—	—	X	X	—	—	—	X	—	—	45
46	—	X	—	X	—	X	—	X	—	—	—	—	U	—	—	—	—	—	X	—	—	—	—	—	X	—	—	U	—	—	X	—	C	—	—	X	X	—	—	—	X	—	—	46
47	—	X	—	—	—	X	—	X	—	—	X	—	U	—	—	—	—	—	X	—	—	—	—	—	X	—	—	U	—	—	X	—	—	—	—	X	X	—	—	—	X	—	—	47
48	—	X	—	—	—	X	—	X	—	—	X	—	U	—	—	—	—	—	X	—	—	—	—	—	X	—	—	U	—	—	X	—	—	—	—	X	X	—	—	—	X	—	—	48
49	—	X	—	—	—	X	—	X	—	—	X	—	U	—	R	—	—	—	X	—	—	—	—	—	X	—	—	U	—	—	X	—	—	—	—	X	X	—	—	—	X	—	—	49
1950	—	X	—	—	—	X	—	—	—	—	X	—	U	—	X	—	—	—	X	—	—	—	X	—	X	—	—	U	—	—	X	—	—	—	—	X	X	—	—	R	X	—	—	1950
51	—	X	—	—	—	X	—	—	—	—	X	—	U	—	X	—	—	—	X	—	—	—	—	—	X	—	—	U	—	—	X	—	—	—	—	X	X	—	—	X	X	—	—	51
52	—	X	—	—	—	X	—	—	—	—	X	—	U	—	X	—	—	—	—	—	—	—	—	—	X	—	—	U	—	—	X	—	—	—	—	X	X	—	—	X	X	—	—	52
53	—	X	—	—	—	X	—	—	—	—	X	—	U	—	X	—	—	—	—	—	—	—	—	—	X	—	—	U	—	—	X	X	—	—	—	X	X	—	—	X	X	—	—	53
54	—	X	—	—	—	X	—	—	—	—	X	—	U	—	X	—	—	—	—	—	—	—	—	—	X	X	—	U	—	—	X	X	—	—	—	X	X	—	—	X	X	—	—	54
55	—	X	—	—	—	X	—	—	—	—	X	—	U	—	—	—	—	—	—	—	—	—	—	—	X	X	—	U	—	—	X	X	—	—	—	X	—	—	—	X	X	—	—	55
56	—	X	—	—	—	X	—	—	—	—	X	—	U	—	—	—	—	—	—	—	—	—	—	—	X	X	—	U	—	—	X	X	—	—	—	X	—	—	—	X	X	—	—	56
57	—	X	—	—	—	X	—	—	—	—	X	—	U	—	X	—	—	—	—	—	—	—	—	—	X	X	—	U	—	—	X	X	—	—	—	X	X	—	—	X	X	—	—	57
58	—	X	—	—	—	X	—	—	—	—	X	—	U	—	X	—	—	—	—	—	—	—	X	—	X	X	—	U	—	—	X	X	—	—	—	X	X	—	—	X	X	—	—	58
59	—	X	—	—	—	X	—	—	—	—	X	—	U	—	—	—	—	—	—	—	—	—	—	—	X	X	—	U	—	—	X	X	—	—	—	X	—	X	—	X	X	—	—	59
1960	—	X	—	—	—	X	—	—	—	—	X	—	U	—	X	—	—	—	—	—	—	—	X	—	X	X	—	U	—	—	X	X	—	—	—	X	X	X	—	X	X	—	—	1960
61	—	X	—	—	—	X	—	—	—	—	X	—	U	—	X	—	—	—	—	—	—	—	X	—	X	X	—	U	X	X	X	X	—	—	—	X	X	X	—	X	X	—	—	61
62	—	X	—	—	—	X	—	—	—	—	X	—	U	—	X	—	—	—	—	—	—	—	X	—	X	X	—	U	X	X	X	X	—	—	—	X	X	X	—	X	X	—	—	62

C=closed by flood; D=destroyed by flood, etc.; E=eyeing station; I=insufficient spawners; P=privately operated; R=relocated; U=operated by U.S. Govt.; X=operated by state

TABLE 13. Continued—Washington (concluded).

Year	WASHINGTON																																			
	Minter Creek	Naselle	Nemah	Nisqually	Nooksack	Nooksack-MF	North River	Ozette Lake	Pilchuck	Puyallup	Quilcene	Quinault	Samish	Samish Lake	Salt Water Experiment	Simpson River	Skagit-Sauk River	Skagit	Skokomish	Skykomish	Snohomish	Spring Creek	Stillaguamish	Sultan	Tahuya	Tilton	Toutle	Washougal	Wenatchee-Leavenworth	Big White Salmon	Little White Salmon	Willard	Willapa	Willapa-Raymond	Wind River	Winthrop
1872	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
73	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
74	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
75	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
76	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
77	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
78	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
79	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1880	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
81	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
82	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
83	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
84	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
85	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
86	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
87	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
88	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
89	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1890	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
92	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
93	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
94	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
96	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
97	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—
98	—	—	—	—	—	—	—	—	—	—	—	—	—	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	U	—	—	—	—	—
99	—	—	—	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	X	—	U	—	—	—	—	—
1900	—	—	—	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	U	U	—	X	—	X	—
01	—	—	—	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	X	U	X	—	—	—	—	—	X	U	U	—	X	—	X	—
02	—	—	—	X	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	X	U	X	—	—	—	—	—	X	U	U	—	X	—	X	—
03	—	—	—	X	—	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	X	U	—	—	—	—	—	—	X	U	U	—	X	—	X	—
04	—	—	—	X	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	X	U	—	—	—	—	—	—	—	U	U	—	X	—	X	—
05	—	—	—	X	X	—	—	—	—	—	—	—	X	—	—	—	X	—	X	—	X	U	—	—	—	—	—	—	—	U	U	—	X	—	X	—
06	—	—	—	X	X	—	—	—	—	—	—	—	X	—	—	—	X	—	X	—	X	U	—	—	—	—	—	—	—	U	U	—	X	—	X	—
07	—	—	—	X	X	—	—	—	—	—	—	—	X	—	—	—	C	—	X	—	X	U	—	—	—	—	—	—	—	U	U	—	X	—	X	—
08	—	—	—	X	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	X	U	—	—	—	—	—	—	—	U	U	—	X	—	X	—
09	—	—	—	X	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	X	U	R	—	—	—	—	—	—	U	U	—	X	—	X	—

1910	—	—	—	X	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	X	U	—	—	—	—	—	—	—	U	U	—	X	—	X	—	1910
11	—	—	—	X	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	X	U	—	—	—	—	—	—	—	U	U	—	X	—	X	—	11
12	—	—	—	X	X	—	—	—	—	—	U	—	X	—	—	—	—	—	X	—	X	U	—	U	—	—	—	—	R	U	U	—	X	—	X	—	12
13	—	—	—	X	X	X	—	—	—	—	U	—	X	—	—	—	R	—	X	—	X	U	X	U	—	—	—	—	X	U	U	—	X	—	X	—	13
14	—	—	—	X	X	X	—	—	—	—	U	U	X	—	—	—	X	—	X	—	X	U	X	U	—	—	—	—	X	U	U	—	X	—	X	—	14
15	—	—	—	X	X	X	X	—	X	—	U	U	X	—	—	—	X	—	X	—	X	U	X	U	—	X	—	—	X	U	U	—	X	—	X	—	15
16	—	—	—	X	X	X	X	—	X	—	U	U	X	—	—	—	X	—	X	—	X	U	X	U	—	X	—	—	X	U	U	—	X	X	X	—	16
17	—	—	—	X	X	X	X	—	X	X	U	U	X	—	—	—	C	—	X	X	X	U	D	U	—	X	—	—	X	U	U	—	X	X	X	—	17
18	—	X	—	X	X	X	X	—	X	X	U	U	X	—	—	—	—	—	X	X	X	U	—	U	—	X	—	—	X	U	U	—	X	X	X	—	18
19	—	X	—	D	X	X	X	—	X	X	U	U	X	—	—	—	—	—	X	X	X	U	—	U	X	X	—	—	X	U	U	—	X	X	X	—	19
1920	—	X	—		X	X	X	—	X	X	U	U	X	—	—	—	—	—	X	X	X	U	—	U	X	X	—	—	X	U	U	—	X	X	X	—	1920
21	—	—	—	—	X	X	X	—	X	X	U	U	X	—	—	—	—	—	C	X	X	U	—	U	—	—	—	—	X	U	U	—	X	C	X	—	21
22	—	—	—	—	I	C	X	—	X	X	U	U	X	—	—	—	—	—		X	—	U	—	U	—	—	—	—	X	U	U	—	X	—	I	—	22
23	—	X	—	—	X	—	X	—	X	X	U	U	X	—	—	—	—	—	—	X	X	U	—	U	—	—	—	—	X	U	U	—	X	—	—	—	23
24	—	X	—	—	X	—	—	—	X	X	U	U	X	—	—	—	—	—	—	X	X	U	—	U	—	—	—	—	U	U	U	—	X	—	—	—	24
25	—	X	—	—	X	—	—	U	X	X	U	U	X	—	X	—	—	—	—	X	X	U	—	U	—	—	—	—	U	U	U	—	X	—	U	—	25
26	—	X	—	—	X	—	—	U	X	X	U	U	X	—	X	—	—	—	—	X	—	U	—	U	—	—	—	—	C	U	U	—	X	—	U	—	26
27	—	X	—	—	X	—	—	C	X	X	U	U	X	—	X	—	—	—	—	X	—	U	—	U	—	—	—	—	X	U	U	—	X	—	—	—	27
28	—	X	—	—	X	—	—	—	X	X	U	U	X	—	X	—	—	—	—	X	—	U	—	U	—	—	—	—	X	U	U	—	X	—	X	—	28
29	—	X	—	—	X	—	—	—	X	X	U	U	X	—	—	—	—	—	—	X	—	U	—	U	—	—	—	—	X	U	U	—	X	—	X	—	29
1930	—	X	—	—	X	—	—	—	X	X	U	U	X	—	—	—	—	—	—	X	—	U		U	—	—	—	—	—	U	U	—	X		X		1930
31	—	X	—	—	X	—	—	—	—	X	U	U	X	—	—	—	—	—	—	X	—	U	—	U	—	—	—	—	—	U	U	—	X	—	X	—	31
32	—	X	—	—	X	—	—	—	—	X	U	U	X	—	—	—	—	—	—	X	—	U	—	—	—	—	—	—	—	U	U	—	X	—	X	—	32
33	—	X	—	—	X	—	—	—	—	X	U	U	X	—	—	—	—	—	—	X		U	—	—	—	—	—	—	—	U	U	—	X	—	X	—	33
34	—	X	—	—	X	—	—	—	—	X	U	U	X	—	—	—	—	—	—	X	—	U	—	U	—	—	—	—	—	U	U	—	X	—	X	—	34
35	—	X	—		X	—	—	—	—	X	U	U	X	—	—	—	—	—	—	X	—	U	—	C		—	—	—	—	U	U	—	X	—	X	—	35
36	X	X	—	—	X	—	—	—	—	X	U	U	X	—	—	—	—	—	—	X	—	U	—	—	—	—	—	—	—	U	U	—	X	—	X	—	36
37	X	X	—	—	X	—	—	—	—	X	U	U	X	—	—	—	—	—	—	X	—	U	—	—	—	—	—	—	—	R	U		X	—	X	—	37
38	X	X	—	—	X	—	—	—	—	X	U	U	X	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	U	U	—	X	—	X	—	38
39	X	X	—	—	C	—	—	—	—	X	U	U	X	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	U	U	—	X	—	C	—	39
1940	X	X	—	—	—	—	—	—	—	X	U	U	X	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	U	U	—	X	—	—	—	1940
41	X	X	—	—	—	—	—	—	—	X	U	U	X	—	—	—	—	—	—	X	—	—	—	—		—	—	—	U	U	U	—	X	—	—	U	41
42	X	X	—	—	—	—	—	—	—	X	U	X	X	—	—	—	—	—	—	X	—	U	—	—	—	—	—	—	U	U	U	—	X	—	—	U	42
43	X	X		—	—	—	—	—	—	X	U	—	X	—	—	—	—	—	—	X	—	U	—	—	—	—	—	—	U	U	U	—	X	—	—	U	43
44	X	X	—		—	—	—	—	—	X	U	—	X	—	X	—	—	—		X	—	U	—	—	—	—		—	U	U	U	—	X	—	—	U	44
45	X	X	—	—	—	—	—	—	—	X	U	—	X	—	X	—	—	—	—	X	—	U	—	—	—	—	—	—	U	U	U	—	X	—	—	U	45
46	X	X	—	—	—	—	—	—	—	X	U	—	X	—	—	—	—	R	—	X	—	U	—	—	—	—	—	—	U	U	U	—	X	—	—	U	46
47	X	X	—	—	—	—	—		—	X	U	—	X	—	—	—	—	X	—	X	—	U	—	—	—	—	—	—	U	U	U	—	X	—	—	U	47
48	X	X	—	—	—	—	—	—	—	X	U	—	X	—	—	—	—	X	—	X	—	U	—	—	—	—	—	—	U	U	U	—	X	—	—	U	48
49	X	X	—	—	—	—	—	—		X	U	—	X		—	X		X	—	X	—	U		—		—	—	—	U	U	U	—	X	—	—	U	49
1950	X	X	—		X		—	—	—	X	U	—	X	—	—	X	—	X	—	X	—	U	—	—	—	—	—	—	U	U	U	—	X	—	—	U	1950
51	X	X	—	—	X	—	—	—	—	X	U	—	X	—	—	X	—	X	—	X	—	U	—	—	—	—	—	—	U	U	U	U	X	—	—	U	51
52	X	X	—	—	X	—	—	—	—	X	U	—	X	—	—	X	—	X	—	X	—	U	—	—	—	—	X	—	U	U	U	U	X	—	—	U	52
53	X	X	X	—	X	—	—	—	—	X	U	—	X	—	—	X	—	X	—	X	—	U	—	—	—	—	X	—	U	U	U	U	X	—	—	U	53
54	X	—	X	—	X	—	—		—	X	U	—	X		—	X	—	X	—	X	—	U	—	—	—	—	X	—	U	U	U	U	X	—	—	U	54
55	X		X	—	X	—	—	—	—	X	U	—	X	—	—	X	—	X	—	X	—	U	—	—	—	—	X	—	U	U	U	U	X	—	—	U	55
56	X	—	X	—	X	—	—	—	—	X	U	—	X	—	—	X	—	X	—	X	—	U	—	—	—	—	X	—	U	U	U	U	X	—	—	U	56
57	X	—	X	—	X	—	—	—	—	X	U	—	X	—	—	X	—	X	—	X	—	U		—		—	X	—	U	U	U	U	X	—	—	U	57
58	X	—	X	—	X		—	—	—	X	U	—	X	—	—	X	—	X		X	—	U	—	—	—	—	X	X	U	U	U	U	X	—	—	U	58
59	X	—	X	—	X	—	—	—	—	X	U	—	X	—	—	X	—	X	—	X	—	U	—	—	—	—	X	X	U	U	U	U	X	—	—	U	59
1960	X	—	X	—	X	—	—	—	—	X	U	—	X	—	—	X	—	X	—	X	—	U	—	—	—	—	X	X	U	U	U	U	X	—	—	U	1960
61	X	—	X	—	X		—	—	—	X	U	—	X	—	—	X	—	X	—	X	—	U	—	—	—	—	X	X	U	U	U	U	X	—	—	U	61
62	X	—	X	—	X	—	—	—	—	X	U	—	X	—	—	X	—	X	—	X	—	U	—	—	—	—	X	X	U	U	U	U	X	—	—	U	62

C=closed by flood; D=destroyed by flood, etc.; E=eyeing station; I=insufficient spawners; P=privately operated; R=relocated; U=operated by U.S. Govt.; X=operated by state

TABLE 14. Present production of salmon hatcheries on the Pacific Coast[1].

State and name	Date established	Production (thousands of fish)				
		Chinook	Coho	Pink	Sockeye	Chum
Alaska State						
Deer Mountain	1955	18.4	101.8			
Eagle River (Fire Lake)	1953		40–180			
Kitoi Bay	1955				1,000	
California State						
Cedar Creek	1955	26.3[2]	177.2			
Darrah Springs	1953		380			
Mt. Shasta	1888	3,600				
Nimbus	1955	13,488.5				
Trinity River	1963	1,848.4	690			
Oregon State						
Alsea	1952		900			
Bandon	1924	100	25			
Big Creek	1938	2,000	2,000			
Bonneville	1909	12,000	1,400			
Butte Falls	1918	50–75				
Cascade	1957	7,500	1,200			
Cedar Creek	1935	200	300			
Gnat Creek	1960	1,000	100			
Klaskanine	1911	250	1,700			
Hood River	1920	100–200				
Marion Forks	1950	2,000				
McKenzie	1905	600				
Metolius[3]	1947	200				
Nehalem	1926		360			
Oak Springs	1920	100				
Oxbow	1938	5,000	500			
Roaring River	1930	14[2]				
Sandy	1951	1,200	1,000			
Siletz	1937		750			
South Santiam	1923	160				
Trask	1914	425	700			
Willamette	1911	4,000				
Washington State						
Bowman's Bay	1947	7.1	146.1			649.3
Dungeness	1902	1,400.5	2,322.2			66.8
Elokomin	1954	2,347.4	834.5			65.8
George Adams	1961	2,699	579.4			750.9
Grays River	1961	1,552.5	858.1			85
Green River	1901	8,743.8	1,380.4			
Hood Canal	1953	3,133.2	380.3	792.9		793[4]
Issaquah	1937	5,324.6	1,027.2			
Kalama River	1959	4,136.4	1,023.4			
Lower Kalama River	1895	1,044.5	423.7			
Klickitat	1950	3,110.3	632.5			
Lewis River[5]	1909	1,473[2]	1,171.6			
Minter Creek	1937	3,101	1,183	1,336.3		1,737.1
Nemah	1953	296.6	460.2			1,205.6
Nooksack	1899	3,373.7	317.1			
Puyallup	1917	989.6	559.5			
Samish	1899	1,952.2	657.1			
Simpson	1949	4,278.8	1,295			291
Skagit	1947	4,771.1	1,491.8			
Skykomish	1905	1,850.1	1,528.3			

Continued . . .

TABLE 14. Continued.

State and name	Date established	Production (thousands of fish)				
		Chinook	Coho	Pink	Sockeye	Chum
Speelyai	1961	1,000–2,000	405.8			
Toutle River	1952	2,580.2	1,435			
Washougal	1958	4,158.5	1,336.1			
Willapa	1899	1,108.4	559.1			
U.S. Government						
Carson	1937	3,700	1,800			
Coleman	1942	17,500				
Eagle Creek	1953	6,500	750			
Entiat	1940		500			
Leavenworth	1938	2,900	1,400		3,500	
Little White Salmon	1898	13,100	2,000			
Quilcene	1911	2,700	1,100			1,500
Spring Creek	1901	11,000				
Willard	1951		2,800			
Winthrop	1940		1,300			

---

[1] These production figures are from 1962–64 records.

[2] 1962–63 releases.

[3] Closed 1964, production figure is for 1962.

[4] Hybrid pink-chum cross.

[5] Out of production in 1964 because of flood.

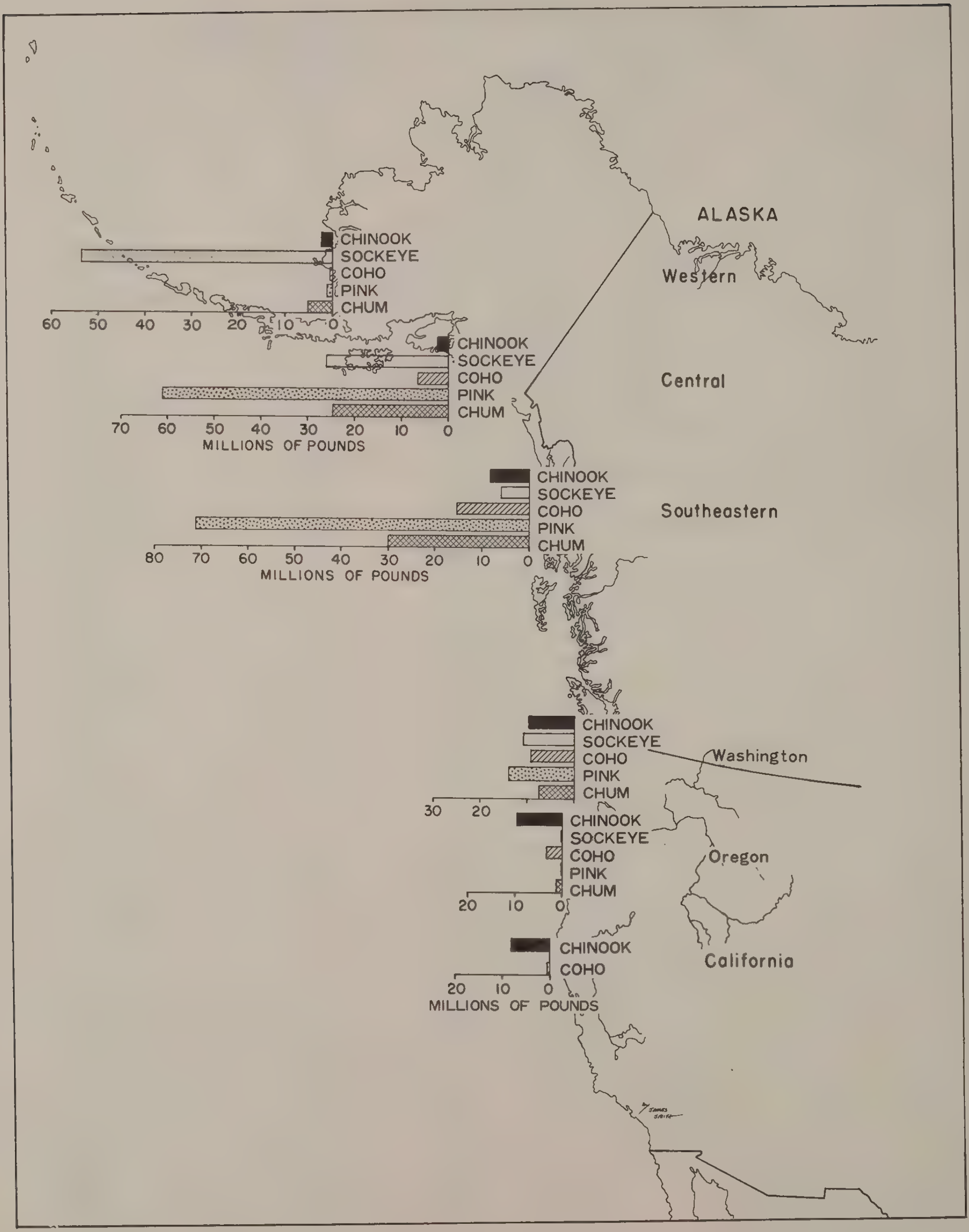


FIGURE 1. Average catches of salmon in the United States over the 25-year period from 1936 to 1960.

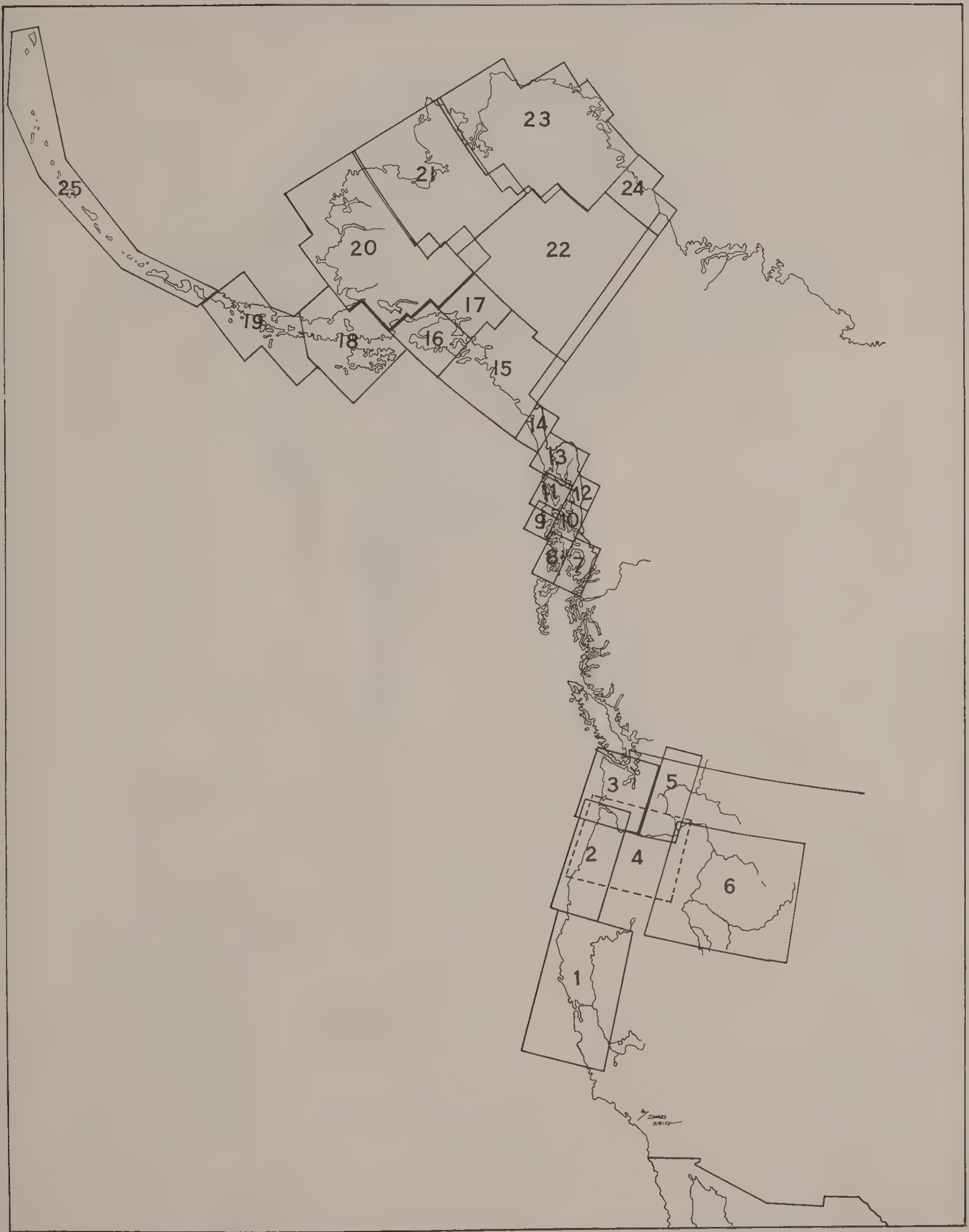
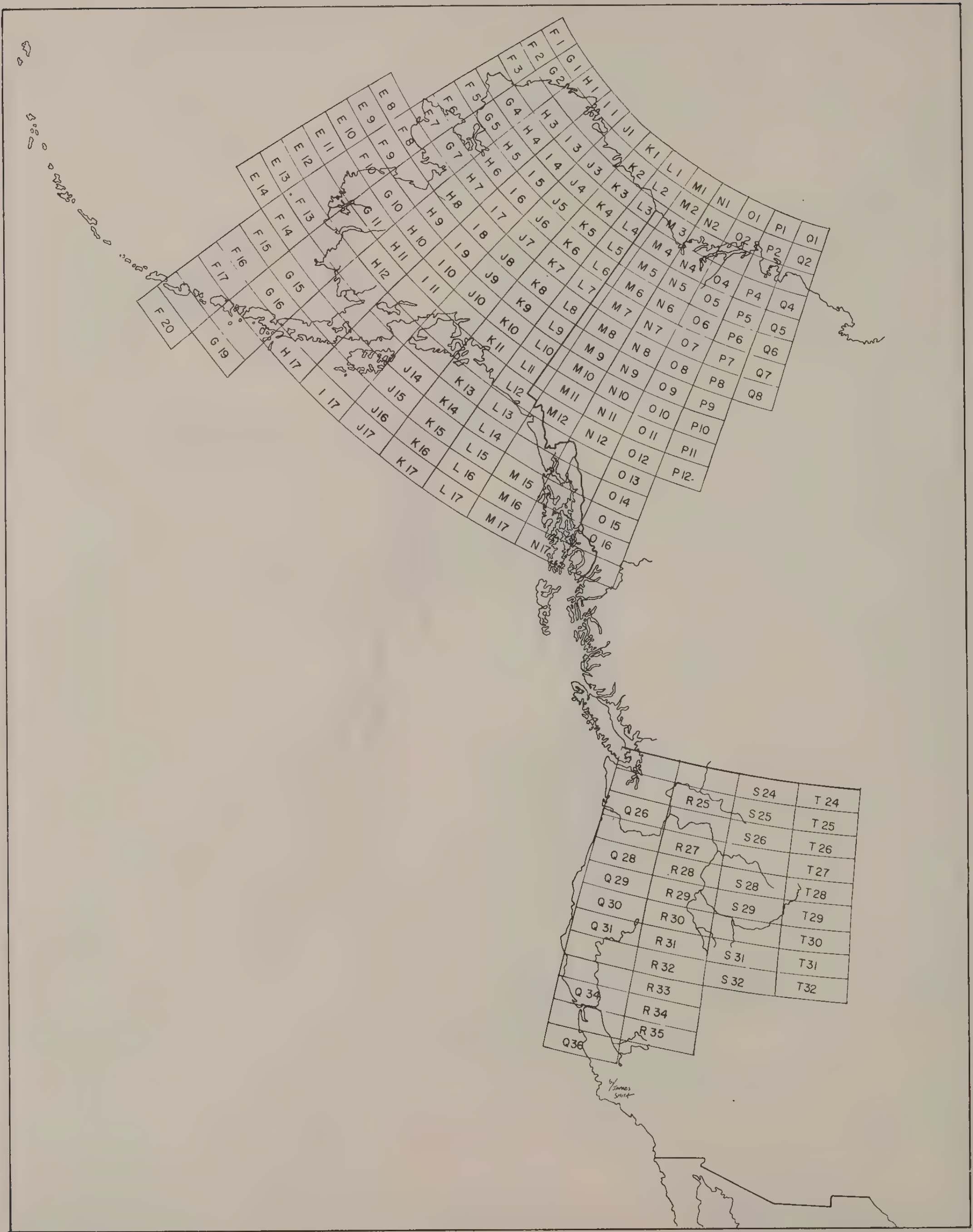

23
21
24
20
22
25
17
19
18
16
15
14
13
11
12
9
10
8
7
3
5
2
4
6
1

FIGURE 2. A key to the subareas used in preparing detailed maps (Figures 5–110) of the spawning grounds of Pacific salmon in the United States (see Table 3).


F1
F2
F3
G1
G2
H1
I1
J1
K1
L1
M1
N1
O1
P1
Q1
E8
E9
E10
E11
E12
E13
E14
F5
F6
F7
F8
F9
F10
F13
F14
F15
F16
F17
F20
G4
G5
G6
G7
G10
G11
G15
G16
G19
H3
H4
H5
H6
H7
H8
H9
H10
H11
H12
H17
I3
I4
I5
I6
I7
I8
I9
I10
I11
I17
J3
J4
J5
J6
J7
J8
J9
J10
J14
J15
J16
J17
K2
K3
K4
K5
K6
K7
K8
K9
K10
K11
K13
K14
K15
K16
K17
L2
L3
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L15
L16
L17
M2
M3
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M8
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M10
M11
M12
M15
M16
M17
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N6
N7
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N9
N10
N11
N12
N17
O2
O4
O5
O6
O7
O8
O9
O10
O11
O12
O13
O14
O15
O16
P2
P4
P5
P6
P7
P8
P9
P10
P11
P12.
Q2
Q4
Q5
Q6
Q7
Q8
S24
T24
R25
S25
T25
Q26
S26
T26
R27
T27
Q28
R28
S28
T28
Q29
R29
S29
T29
Q30
R30
T30
Q31
R31
S31
T31
R32
S32
T32
R33
Q34
R34
R35
Q36

FIGURE 3. A key to coordinates used in Appendices I and II to indicate locations of individual spawning streams. These coordinates are also indicated in Figures 5–110. (See Table 4.)

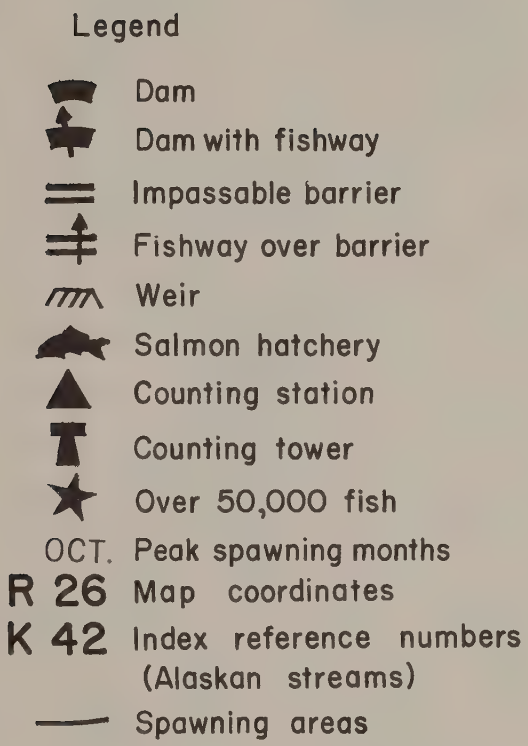
Legend
Dam
Dam with fishway
Impassable barrier
Fishway over barrier
Weir
Salmon hatchery
Counting station
Counting tower
Over 50,000 fish
OCT. Peak spawning months
R 26 Map coordinates
K 42 Index reference numbers (Alaskan streams)
Spawning areas

FIGURE 4. Legend for salmon distribution maps Figures 5–110.

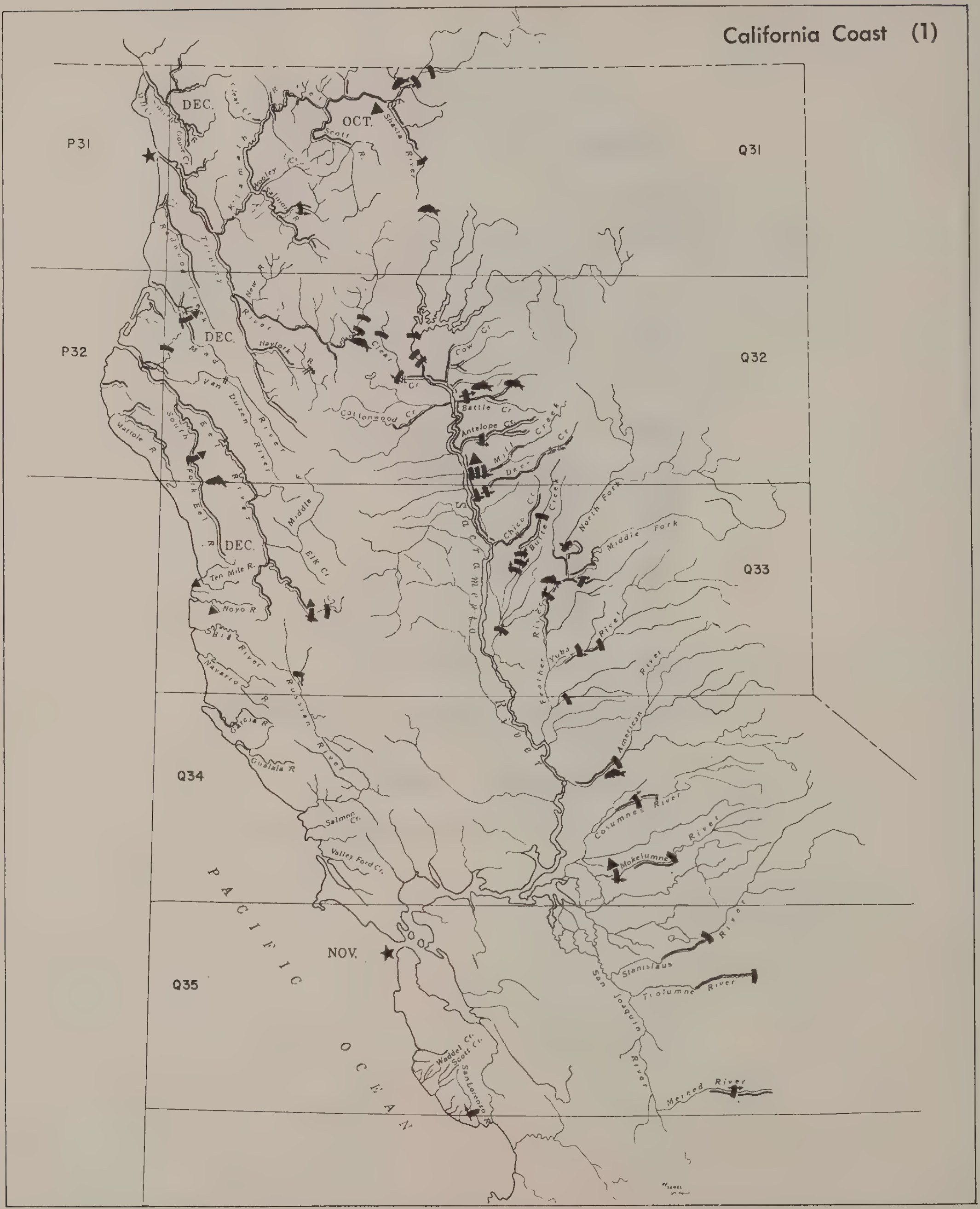
California Coast (1)
P31
Q31
P32
Q32
Q33
Q34
Q35
DEC.
OCT.
DEC.
DEC.
NOV.
Smith R
Goose Cr
Clear Cr
Klamath R
Scott R
Shasta River
Wooley Cr
Salmon R
Redwood Creek
Trinity River
New R
Hayfork R
Clear Cr
Cow Cr
Mad R
Van Duzen River
Battle Cr
Cottonwood Cr
Antelope Cr
Mill Creek
Deer Cr
Mattole R
South Fork Eel R
Eel River
Middle
Elk Cr
Chico Cr
Butte Creek
North Fork
Middle Fork
Sacramento River
Ten Mile R.
Noyo R
Big River
Navarro R
Russian River
Feather River
Yuba River
American River
Garcia R
Gualala R
Salmon Cr.
Valley Ford Cr.
Cosumnes River
Mokelumne River
PACIFIC OCEAN
Stanislaus River
Tuolumne River
San Joaquin River
Waddel Cr.
Scott Cr.
San Lorenzo R
Merced River

Figure 5. Spawning grounds of chinook salmon on California coast.

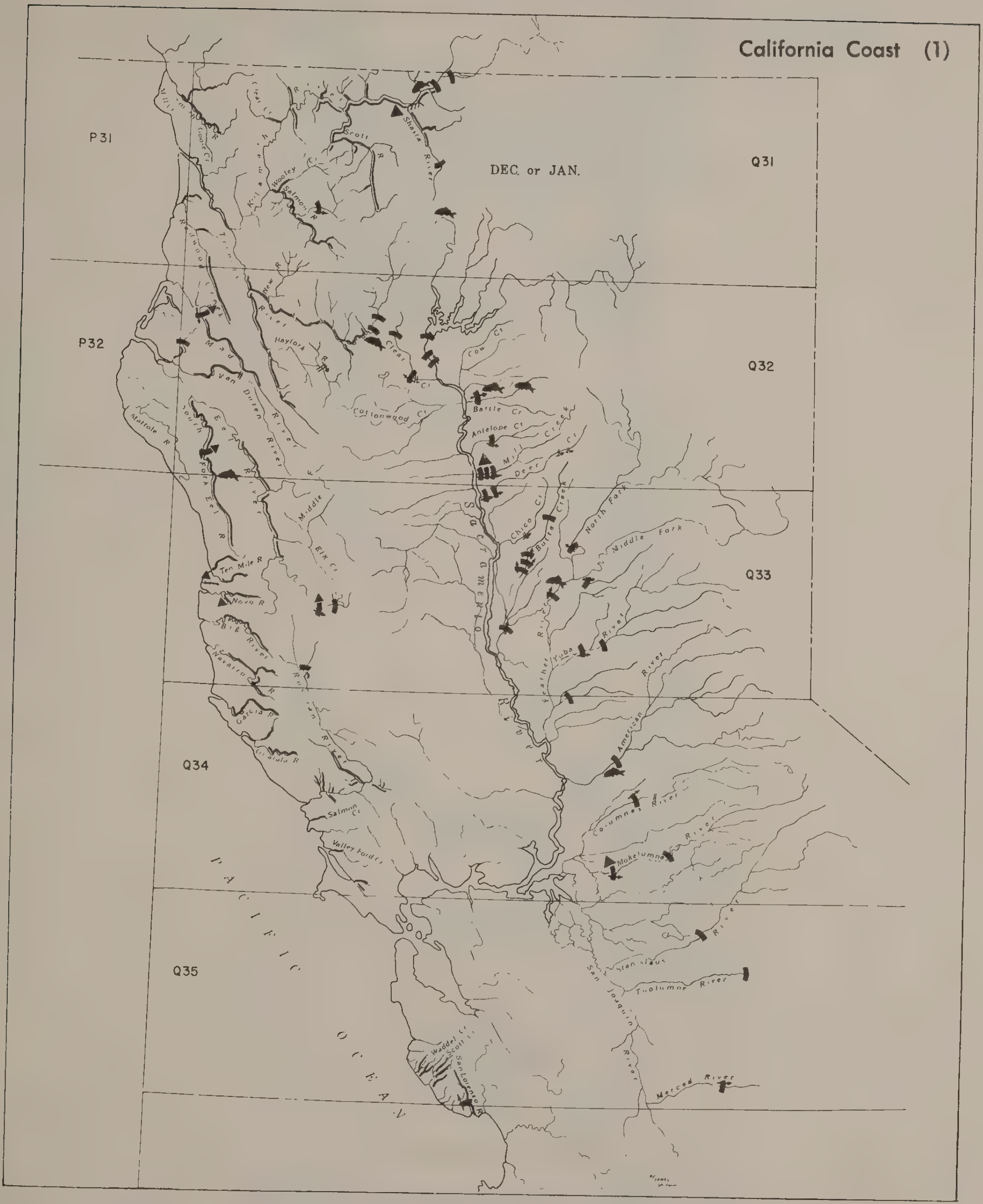
California Coast (1)
P31
Q31
DEC. or JAN.
P32
Q32
Q33
Q34
Q35
Klamath R
Scott R
Shasta River
Salmon R
Wooley Cr
Redwood Creek
Trinity River
New River
Hayfork Cr
Clear Cr
Cow Cr
Cottonwood Cr
Battle Cr
Antelope Cr
Mill Creek
Deer Cr
Mad R
Van Duzen River
Mattole R
South Fork Eel R
Eel River
Middle Fork
Elk Cr
Sacramento River
Chico Cr
Butte Creek
North Fork
Middle Fork
Feather River
Yuba River
American River
Cosumnes River
Mokelumne River
Stanislaus
Tuolumne River
San Joaquin River
Merced River
Ten Mile R
Noyo R
Big River
Navarro R
Garcia R
Gualala R
Russian River
Salmon Cr
Valley Ford Cr
Waddell Cr
Scott Cr
San Lorenzo R
PACIFIC OCEAN

FIGURE 6. Spawning grounds of coho salmon on California coast.

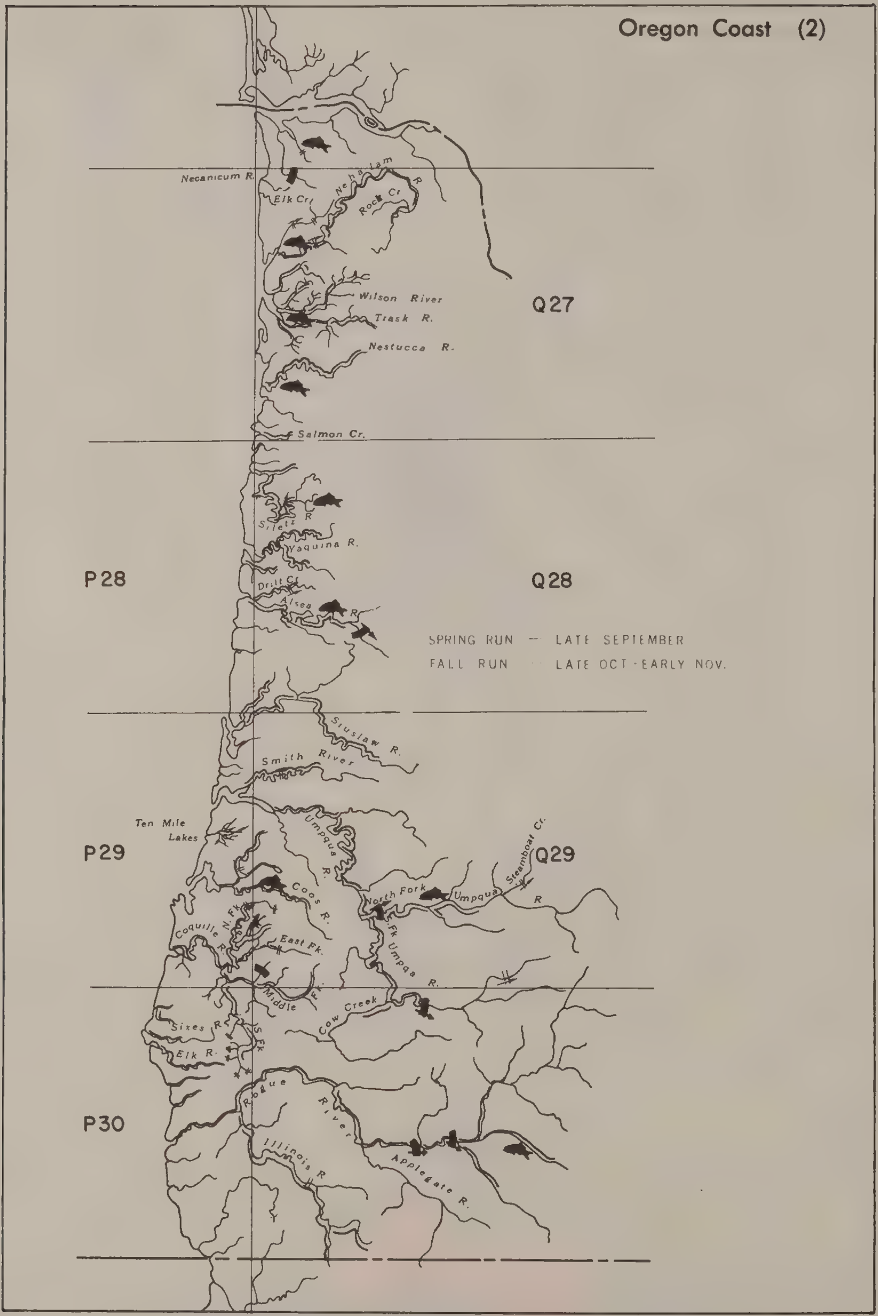
Oregon Coast (2)
Necanicum R.
Elk Cr.
Nehalem R.
Rock Cr.
Wilson River
Trask R.
Nestucca R.
Q27
Salmon Cr.
Siletz R.
Yaquina R.
P28
Q28
Drift Cr.
Alsea R.
SPRING RUN — LATE SEPTEMBER
FALL RUN ··· LATE OCT - EARLY NOV.
Siuslaw R.
Smith River
Ten Mile Lakes
P29
Umpqua R.
Steamboat Cr.
Q29
Coos R.
North Fork Umpqua R
N. Fk
Coquille R.
East Fk.
S. Fk Umpqua R.
Middle Fk
Cow Creek
Sixes R.
S. Fk
Elk R.
Rogue River
P30
Illinois R.
Applegate R.

Figure 7. Spawning grounds of chinook salmon on Oregon coast.

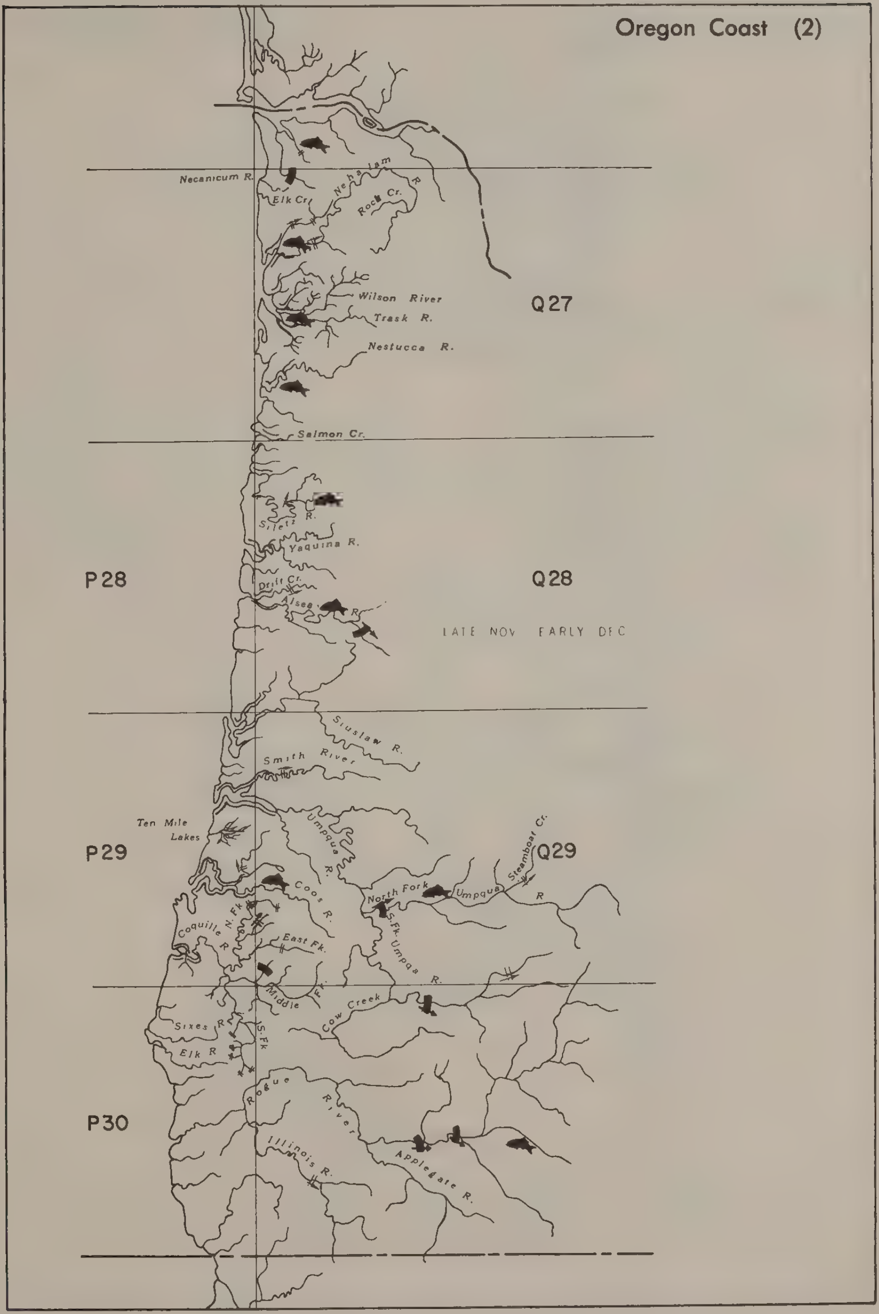
Oregon Coast (2)
Necanicum R.
Elk Cr.
Nehalem R.
Rock Cr.
Wilson River
Trask R.
Q27
Nestucca R.
Salmon Cr.
Siletz R.
Yaquina R.
P28
Drift Cr.
Q28
Alsea R.
LATE NOV EARLY DEC
Siuslaw R.
Smith River
Ten Mile Lakes
Umpqua R.
P29
Steamboat Cr.
Q29
Coos R.
North Fork
Umpqua
R
N. Fk.
Coquille R.
East Fk.
S. Fk. Umpqua R.
Middle Fk.
Cow Creek
Sixes R.
S. Fk.
Elk R.
Rogue River
P30
Illinois R.
Applegate R.

FIGURE 8. Spawning grounds of chum salmon on Oregon coast.

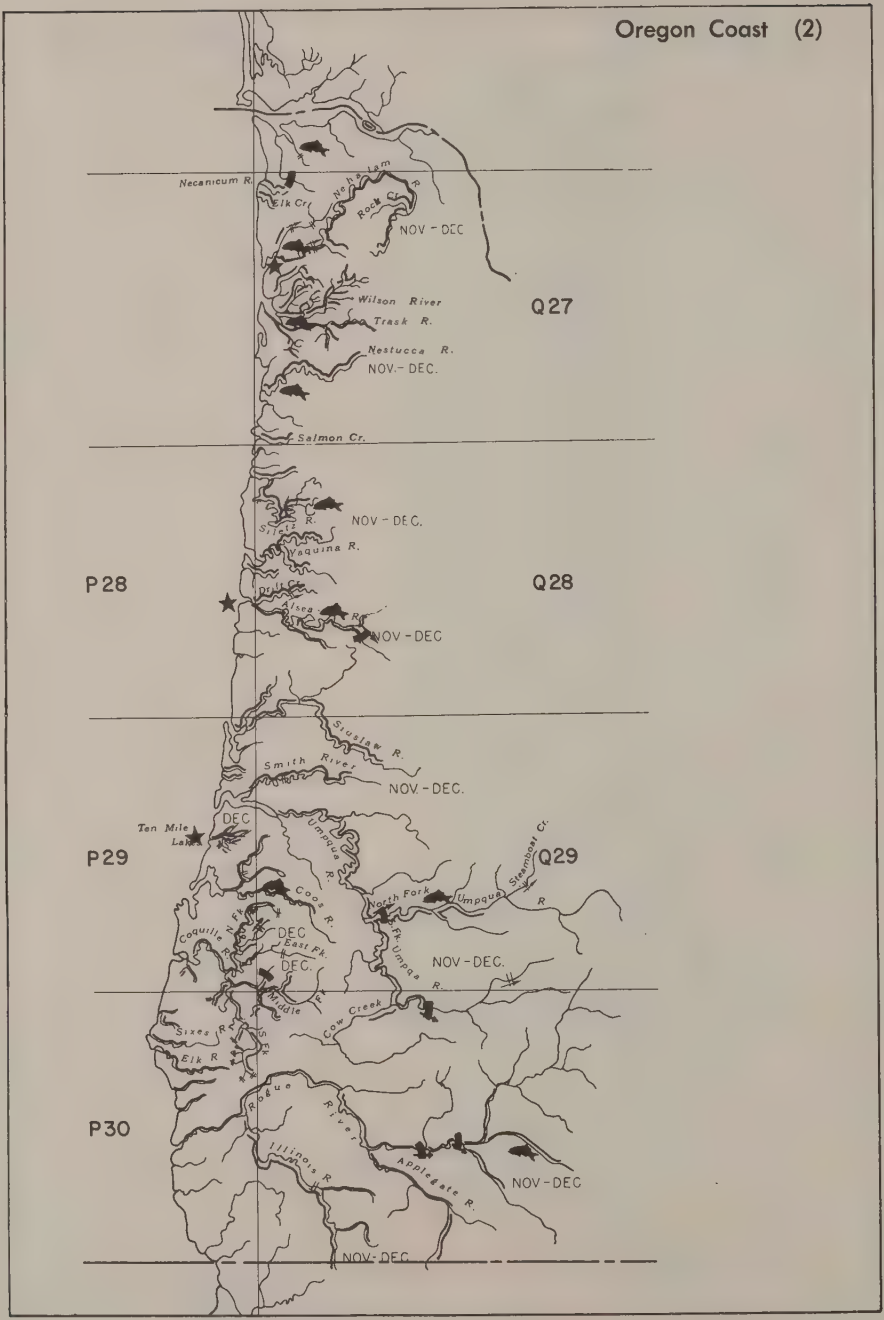
Oregon Coast (2)
Necanicum R.
Elk Cr.
Nehalem R.
Rock Cr.
NOV - DEC
Wilson River
Trask R.
Q27
Nestucca R.
NOV.- DEC.
Salmon Cr.
Siletz R.
NOV - DEC.
Yaquina R.
P28
Q28
Drift Cr.
Alsea R.
NOV - DEC
Siuslaw R.
Smith River
NOV. - DEC.
DEC
Ten Mile Lakes
Umpqua R.
Steamboat Cr.
P29
Q29
Coos R.
North Fork Umpqua R
N. Fk.
Coquille R.
DEC
East Fk.
DEC.
S. Fk. Umpqua R.
NOV - DEC.
Middle Fk.
Cow Creek
Sixes R
S. Fk.
Elk R
Rogue River
P30
Illinois R
Applegate R.
NOV - DEC
NOV - DEC

Figure 9. Spawning grounds of coho salmon on Oregon coast.

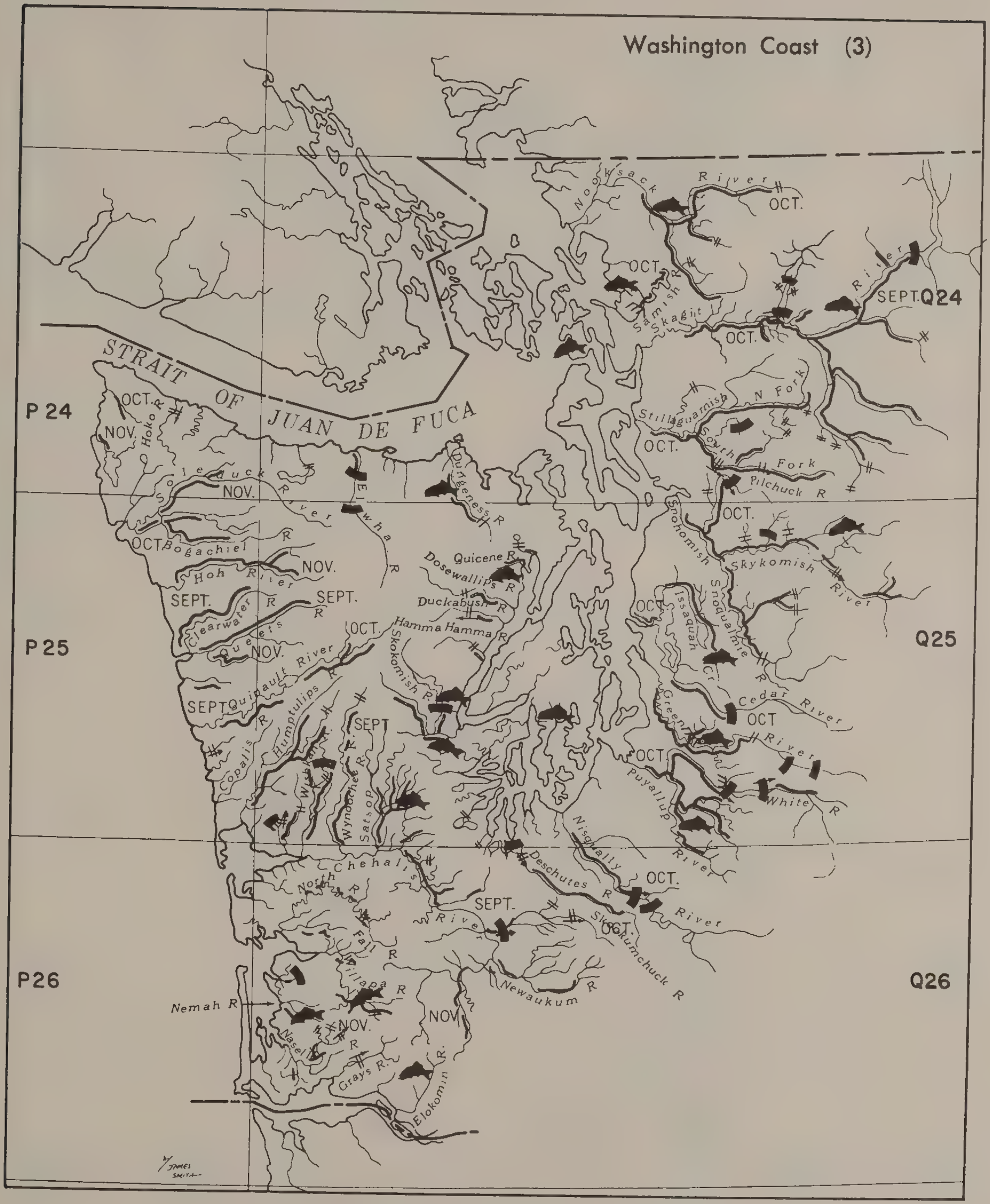
Washington Coast (3)
P 24
P 25
P26
Q24
Q25
Q26
STRAIT OF JUAN DE FUCA
Nooksack River
OCT.
OCT.
Samish R
Skagit
OCT.
River
SEPT.
Stillaguamish
N Fork
OCT.
South Fork
Pilchuck R
OCT.
Snohomish
Skykomish River
OCT.
Issaquah Cr
Snoqualmie R
Cedar River
OCT
Green River
OCT
Puyallup River
White R
Nisqually River
OCT.
Deschutes R
Skookumchuck R
OCT.
Newaukum R
SEPT.
Chehalis River
North R
Fall R
Willapa R
Nemah R
NOV.
Nasel R
Grays R.
NOV
Elokomin R.
OCT.
Hoko R
NOV.
Soleduck River
NOV.
Elwha R
Dungeness R
OCT
Bogachiel R
Hoh River
NOV.
SEPT.
Clearwater R
SEPT.
R
Queets
NOV.
OCT.
Quinault River
SEPT
Quicene R
Dosewallips R
Duckabush R
Hamma Hamma R
Skokomish R
Humptulips R
Copalis R
Wishkah R.
SEPT
Wynoochee R.
Satsop
by James Smith

Figure 10. Spawning grounds of chinook salmon on Washington coast.

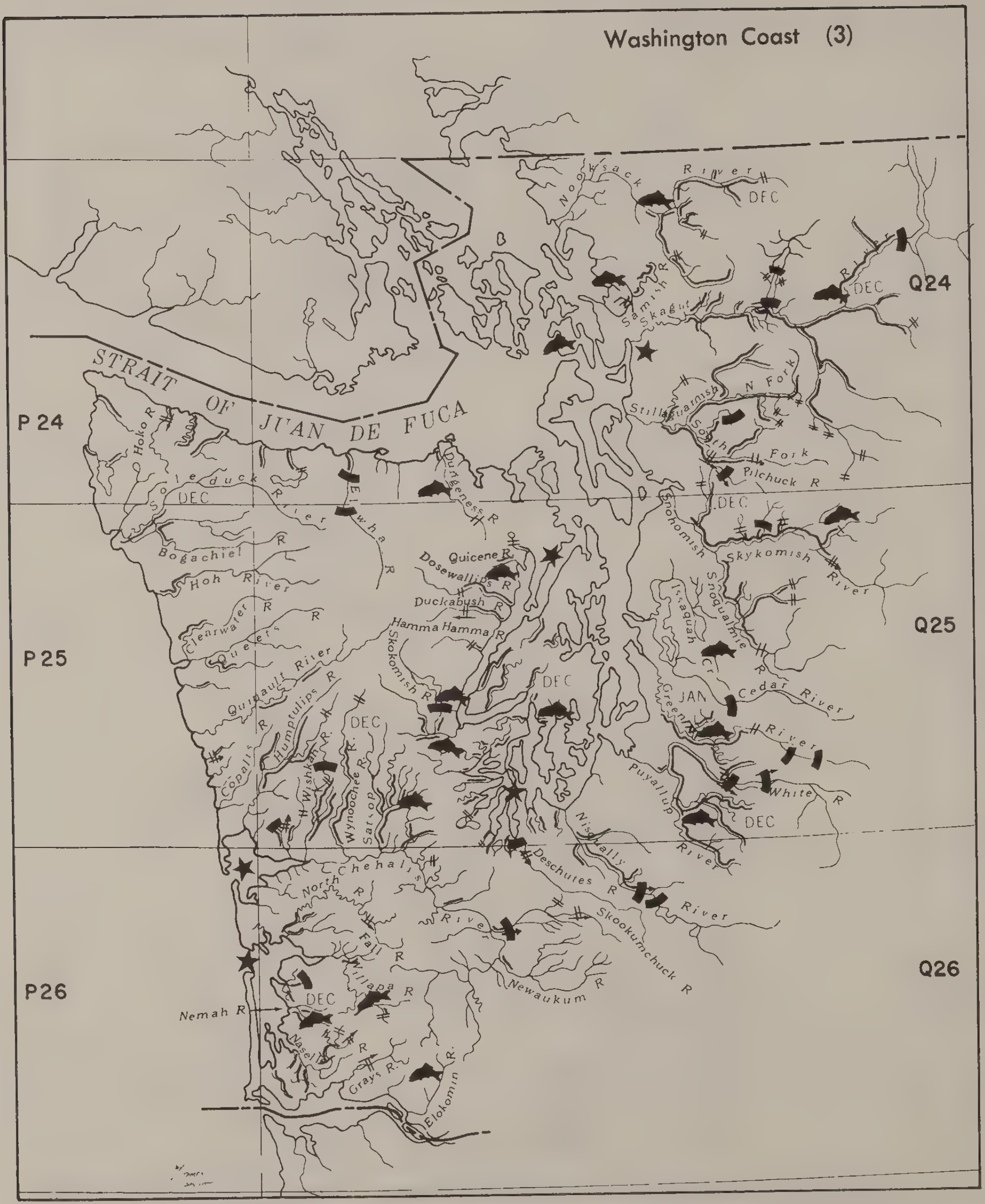
Washington Coast (3)
STRAIT OF JUAN DE FUCA
P 24
P 25
P 26
Q24
Q25
Q26
Nooksack River
DEC
Samish R
Skagit
River
Stillaguamish
N Fork
South Fork
Pilchuck R
Snohomish
Skykomish River
Snoqualmie R
Issaquah Cr
Cedar River
JAN
Green River
White R
Puyallup River
Nisqually River
Deschutes R
Skookumchuck R
Newaukum R
Chehalis River
North R
Fall R
Willapa R
Nemah R
Naselle R
Grays R
Elokomin R
Hoko R
Soleduck River
Elwha R
Dungeness R
Bogachiel R
Hoh River
Clearwater R
Queets R
Quinault River
Humptulips R
Copalis R
Wishkah R
Wynoochee R
Satsop R
Skokomish R
Hamma Hamma R
Duckabush R
Dosewallips R
Quicene R

Figure 11. Spawning grounds of chum salmon on Washington coast.

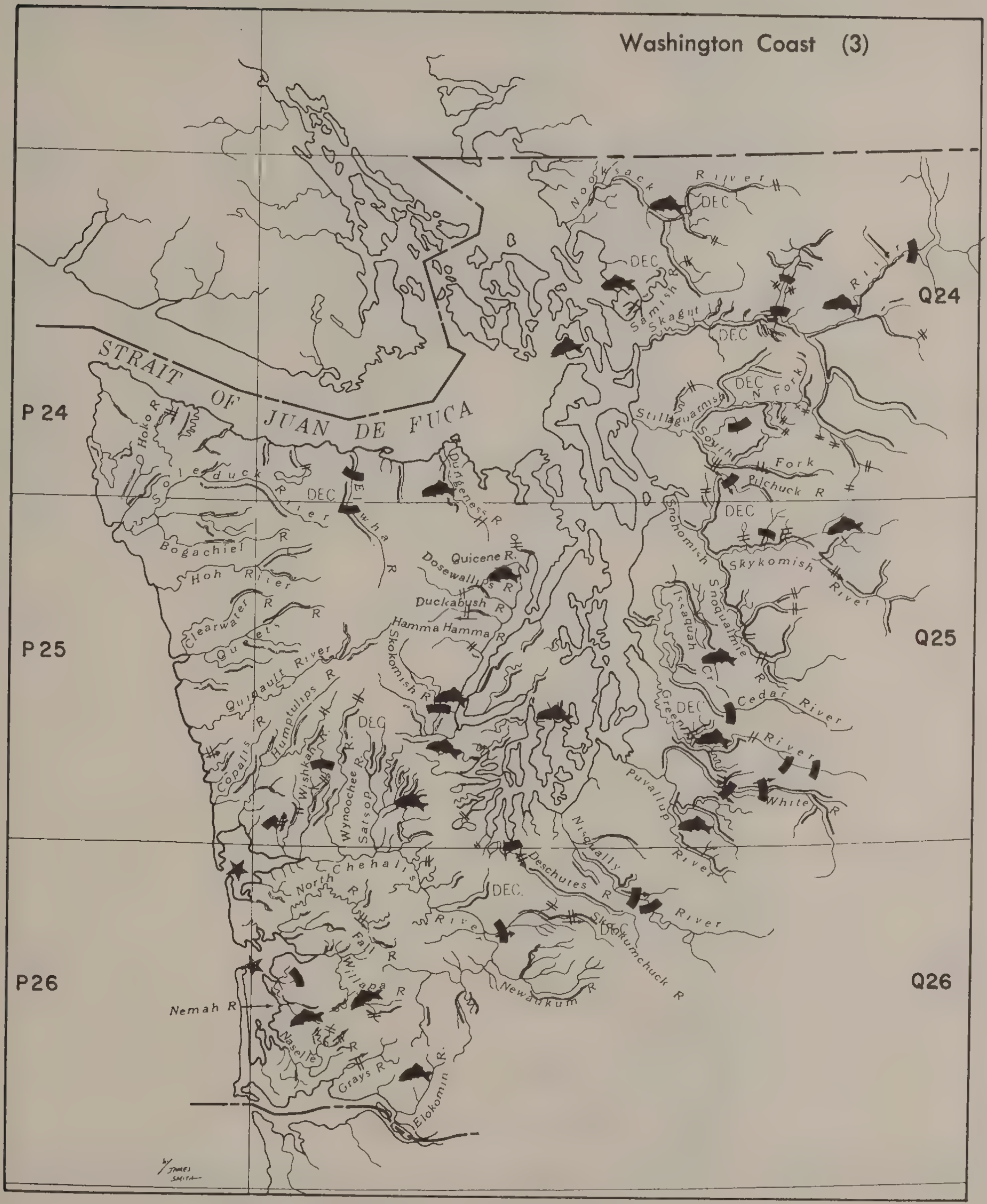
Washington Coast (3)
P 24
P 25
P 26
Q24
Q25
Q26
STRAIT OF JUAN DE FUCA
Nooksack River
DEC
Samish R
Skagit
Skagit River
Stillaguamish
N Fork
South Fork
Pilchuck R
Snohomish
Skykomish River
Snoqualmie R
Issaquah Cr
Cedar River
Green River
White R
Puyallup River
Nisqually River
Deschutes R
Skookumchuck R
Newaukum R
Hoko R
Soleduck River
Elwha R
Dungeness R
Quicene R.
Dosewallips R
Duckabush R
Hamma Hamma R
Skokomish R
Bogachiel R
Hoh River
Clearwater R
Queets R
Quinault River
Humptulips R
Copalis R
Wishkah R.
Wynoochee R.
Satsop
Chehalis River
North R
Fall R
Willapa R
Nemah R
Naselle R
Grays R
Elokomin R.
by James Smith

Figure 12. Spawning grounds of coho salmon on Washington coast.

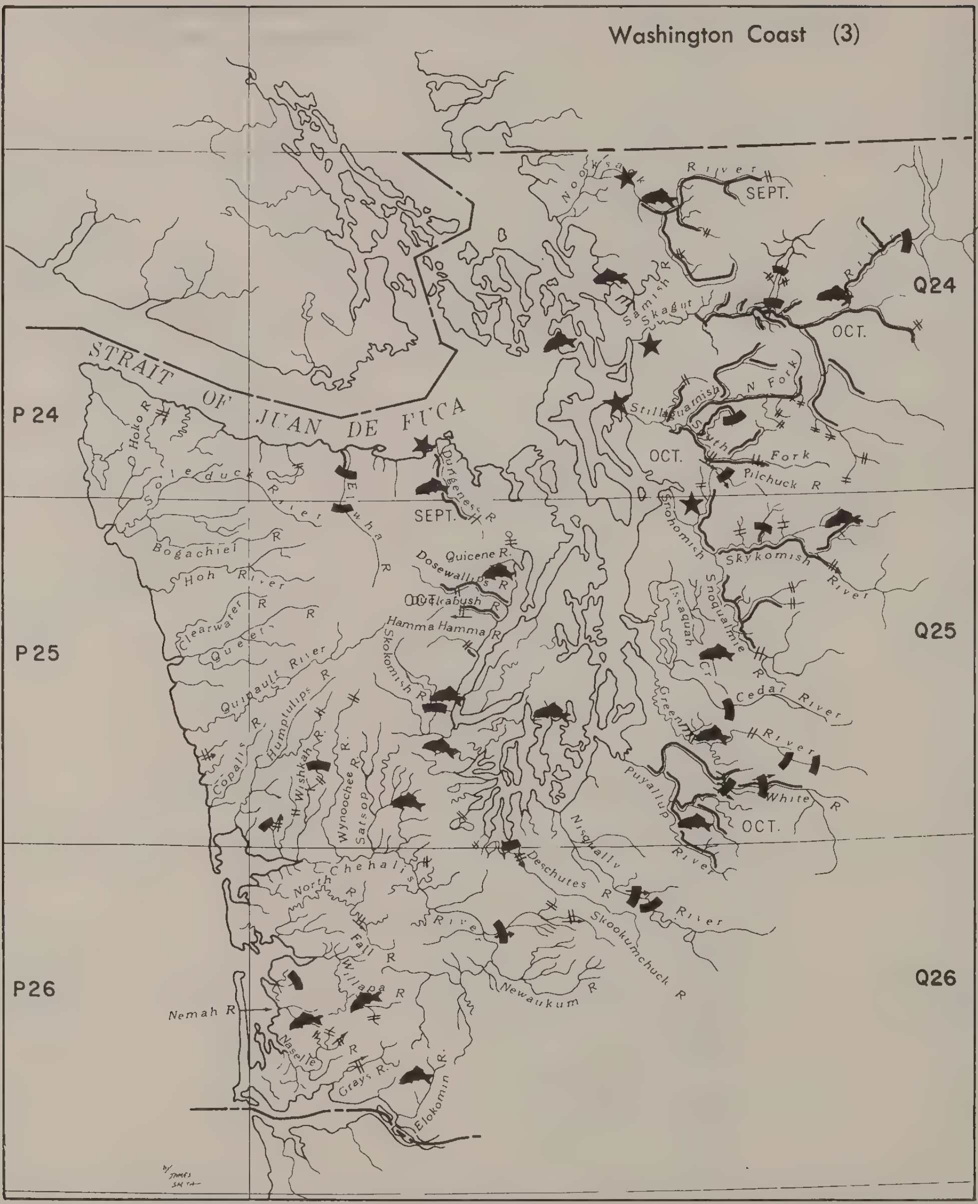
Washington Coast (3)
Nooksack River
SEPT.
Q24
Samish R
Skagit
OCT.
Stillaguamish
N Fork
South Fork
OCT.
Pilchuck R
Snohomish
Skykomish River
Snoqualmie R
Issaquah Cr
Q25
Cedar River
Green River
White R
Puyallup River
OCT.
Nisqually River
Deschutes R
Skookumchuck R
Newaukum R
Q26
STRAIT OF JUAN DE FUCA
P 24
Hoko R
Soleduck River
Elwha R
Dungeness R
SEPT.
Bogachiel R
Hoh River
Quilcene R.
Dosewallips R
OCT.
Duckabush R
Hamma Hamma R
Clearwater R
Queets R
Quinault River
Humptulips R
Skokomish R
P 25
Copalis R
Wishkah R.
Wynoochee R.
Satsop R
Chehalis River
North R
Fall R
Willapa R
P 26
Nemah R
Naselle R
Grays R.
Elokomin R.

Figure 13. Spawning grounds of pink salmon on Washington coast.

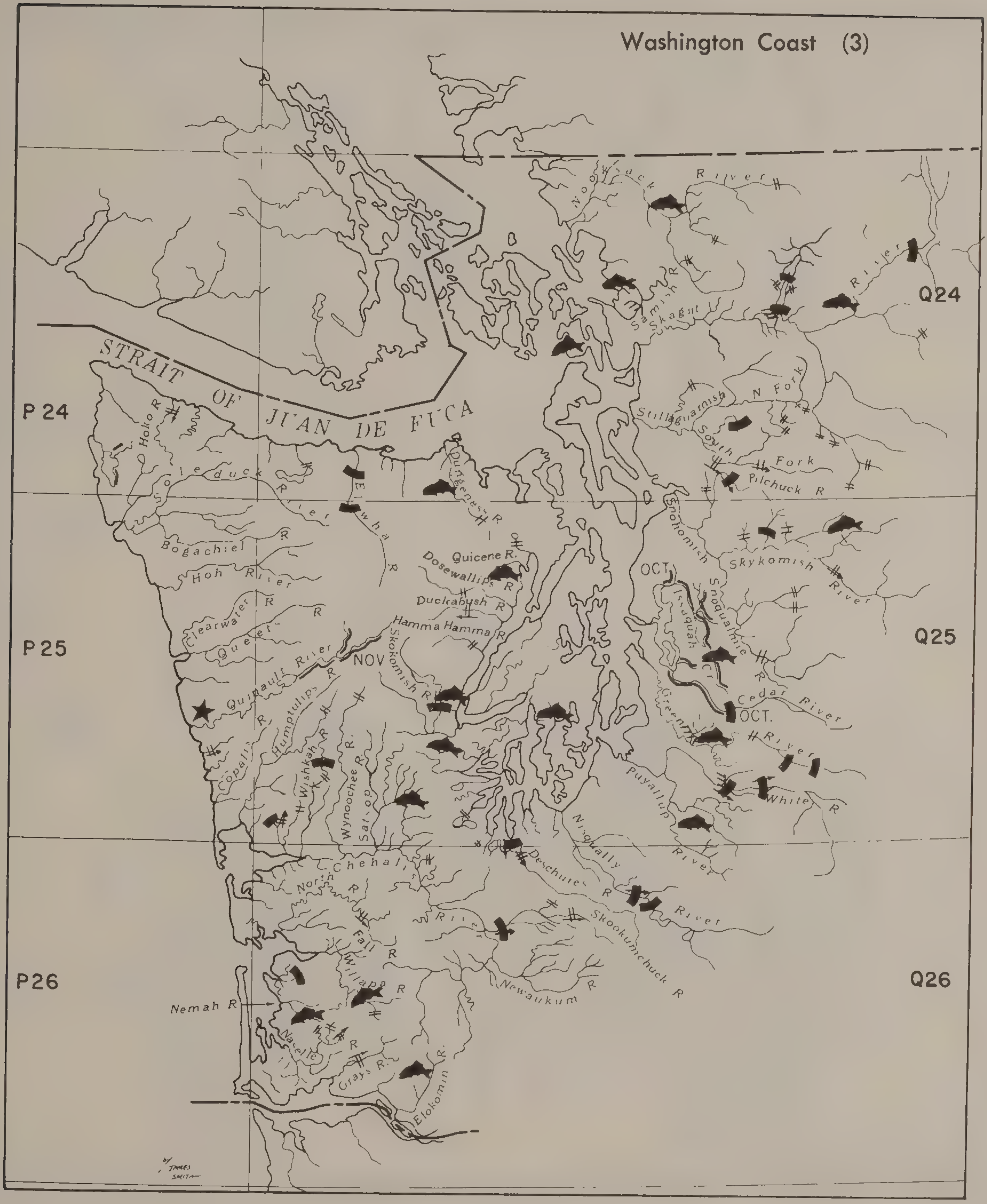
Washington Coast (3)
P 24
P 25
P 26
Q24
Q25
Q26
STRAIT OF JUAN DE FUCA
Nooksack River
Samish R
Skagit River
Stillaguamish
N Fork
South Fork
Pilchuck R
Snohomish
Skykomish River
Snoqualmie R
Issaquah
OCT.
Cedar River
Green River
White R
Puyallup River
Nisqually River
Deschutes R
Skookumchuck R
Newaukum R
Hoko R
Soleduck River
Elwha R
Dungeness R
Bogachiel R
Hoh River
Clearwater R
Queets R
Quinault River
Quicene R.
Dosewallips R
Duckabush R
Hamma Hamma R
Skokomish R
NOV
Humptulips R
Copalis R
Wishkah R
Wynoochee R.
Satsop R
Chehalis R
North R
Fall R
Willapa R
Nemah R
Naselle R
Grays R.
Elokomin R.
by James Smith

FIGURE 14. Spawning grounds of sockeye salmon on Washington coast.

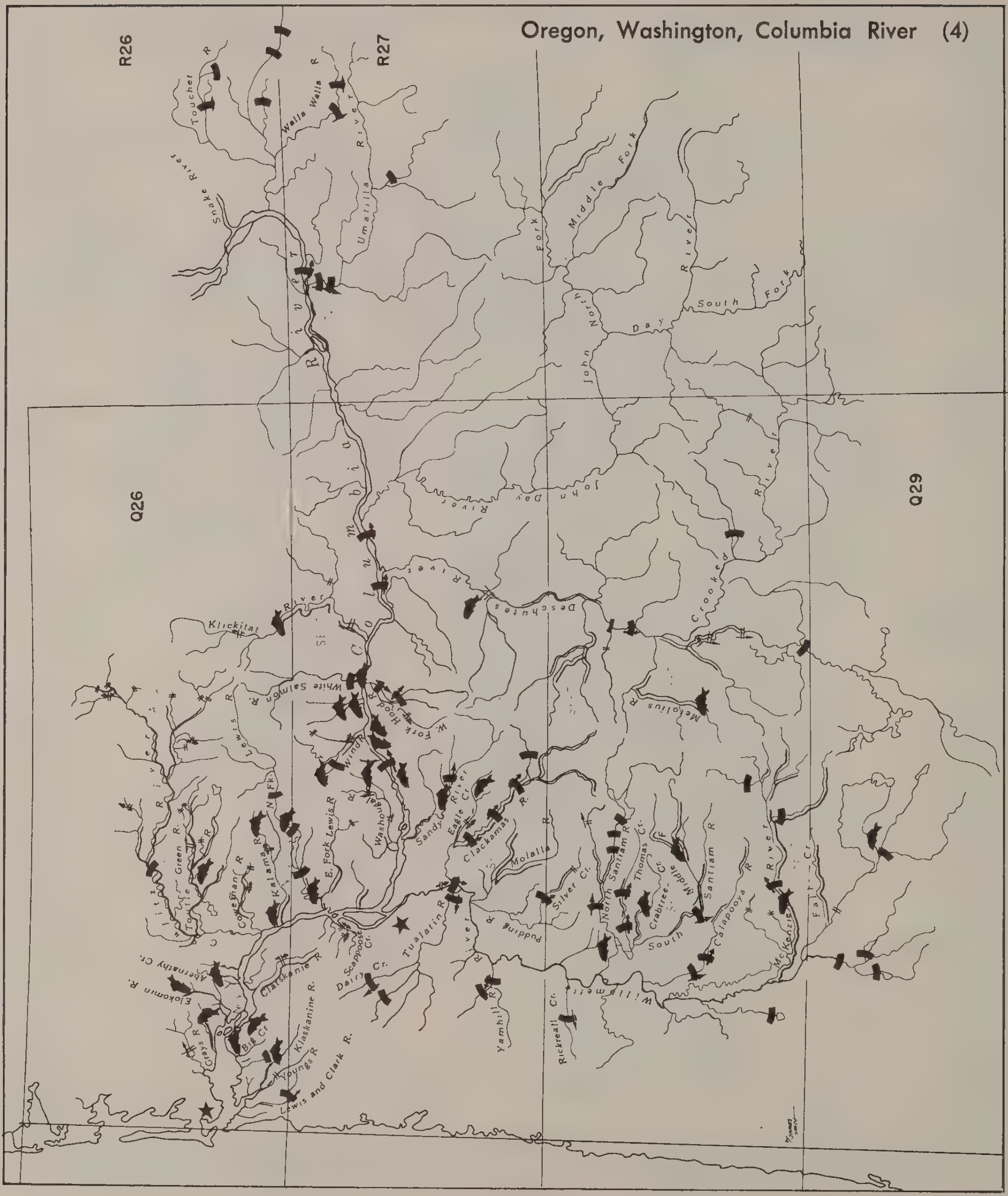
Oregon, Washington, Columbia River (4)
R26
R27
Q26
Q29
Touchet R.
Walla Walla R.
Snake River
Umatilla River
Columbia River
Middle Fork
North Fork
John Day River
South Fork
Deschutes River
Crooked River
Metolius R.
Klickitat River
White Salmon R.
Hood R.
W. Fork Hood R.
Wind R.
Washougal R.
Lewis R.
N. Fk.
E. Fork Lewis R.
Kalama R.
Coweeman R.
Green R.
Toutle R.
Sandy River
Eagle Cr.
Clackamas R.
Molalla R.
Pudding R.
Silver Cr.
North Santiam R.
Thomas Cr.
Crabtree Cr.
Middle
South Santiam R.
Calapooya R.
McKenzie River
Fall Cr.
Willamette
Tualatin R.
Dairy Cr.
Scappoose Cr.
Yamhill R.
Rickreall Cr.
Clatskanie R.
Abernathy Cr.
Elokomin R.
Grays R.
Big Cr.
Klaskanine R.
Youngs R.
Lewis and Clark R.

FIGURE 15. Spawning grounds of chinook salmon on Columbia River.

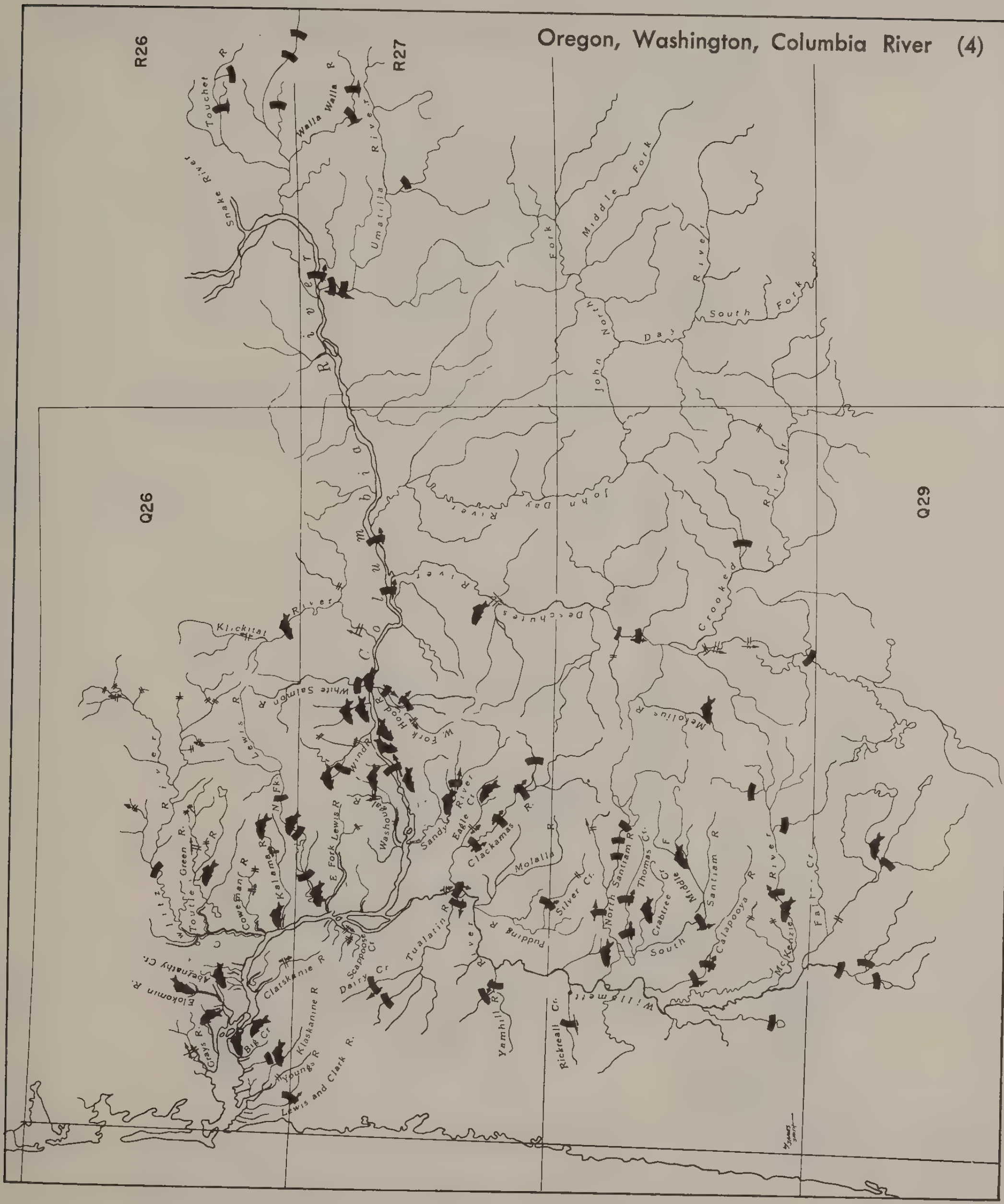
Oregon, Washington, Columbia River (4)
R26
R27
Q26
Q29
Touchet R
Walla Walla R
Snake River
Walla Walla River
Umatilla
Columbia River
Middle Fork
North Fork
John Day River
South Fork
John Day River
Crooked River
Deschutes River
Klickitat River
White Salmon R
Lewis R
Hood R
W. Fork Hood
Wind R
Metolius R
Cowlitz River
Green R.
Toutle R
Coweman R
Kalama R
N. Fk.
E Fork Lewis R
Washougal R
Sandy River
Eagle Cr.
Clackamas R.
Molalla R
Silver Cr.
North Santiam R
Thomas Cr.
Crabtree Cr.
Middle F
South Santiam R
Calapooya R
McKenzie River
Fall Cr.
Pudding R
Tualatin R
Scappoose Cr.
Dairy Cr
Clatskanie R
Abernathy Cr.
Elokomin R.
Grays R.
Big Cr
Klaskanine R
Youngs R
Lewis and Clark R.
Yamhill R.
Rickreall Cr.
Willamette River

Figure 16. Spawning grounds of chum salmon on Columbia River.

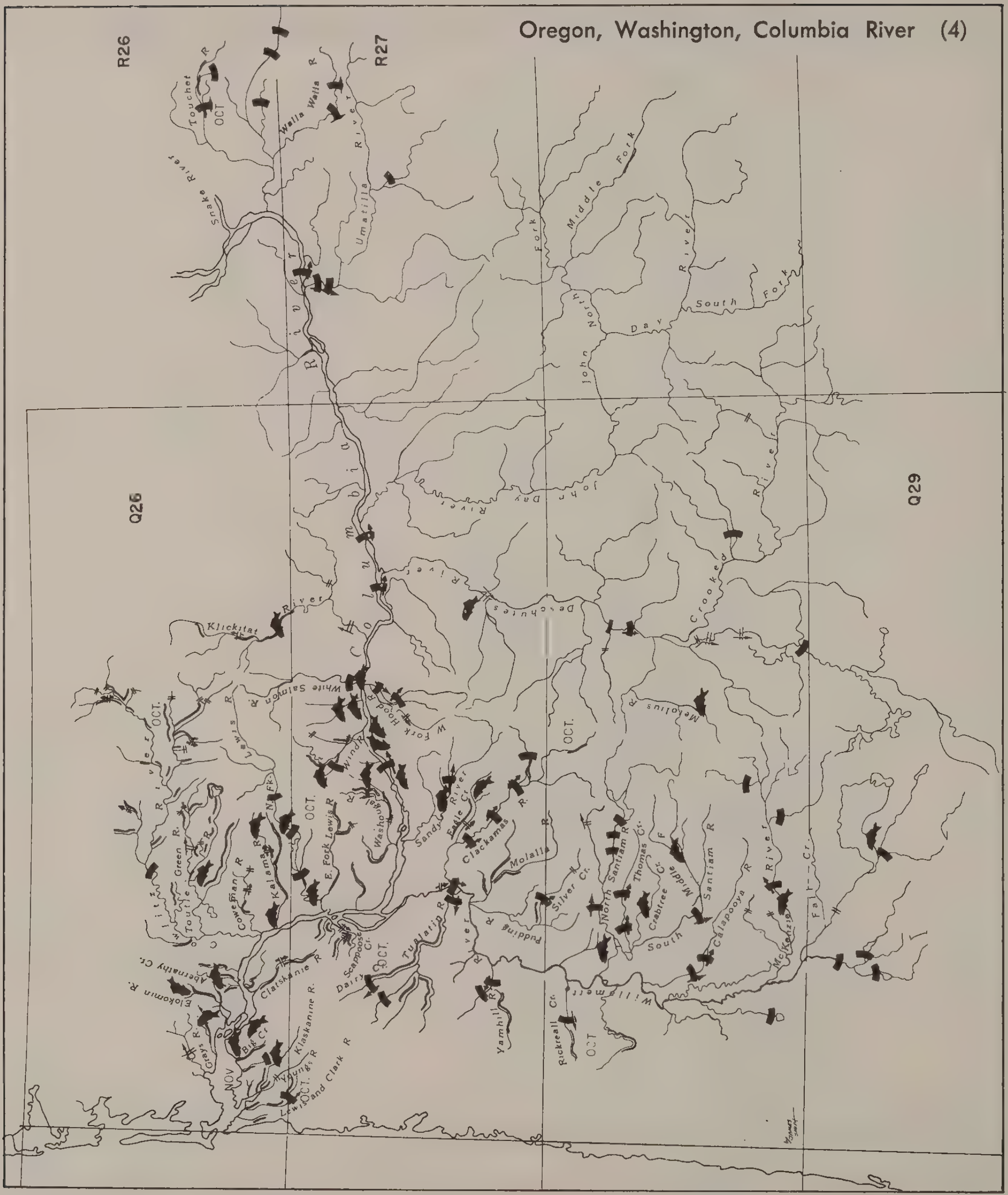
Oregon, Washington, Columbia River (4)
R26
R27
Q26
Q29
Touchet R
OCT
Walla Walla R
Walla Walla River
Snake River
Umatilla R
Columbia River
Middle Fork
Fork
North Fork
John Day River
South Fork
Day
John Day River
Crooked River
Deschutes River
Klickitat River
White Salmon R
Hood R
W Fork Hood R
Metolius R
Lewis R
Cowlitz River
OCT.
Wind R
Washougal R
E. Fork Lewis R
N. Fk.
Kalama R
Coweeman R
Toutle R
Green R
Sandy River
Eagle Cr.
Clackamas R.
Molalla R
Silver Cr.
North Santiam R
Thomas Cr.
Crabtree Cr.
Middle F
Santiam R
South Santiam
Calapooya R
McKenzie River
Fall Cr.
Pudding River
Tualatin R
Scappoose Cr.
Dairy Cr.
Clatskanie R
Abernathy Cr.
Elokomin R.
Grays R
Big Cr.
Klaskanine R.
Youngs R
Lewis and Clark R
NOV.
Yamhill R
Rickreall Cr.
Willamette

FIGURE 17. Spawning grounds of coho salmon on Columbia River.

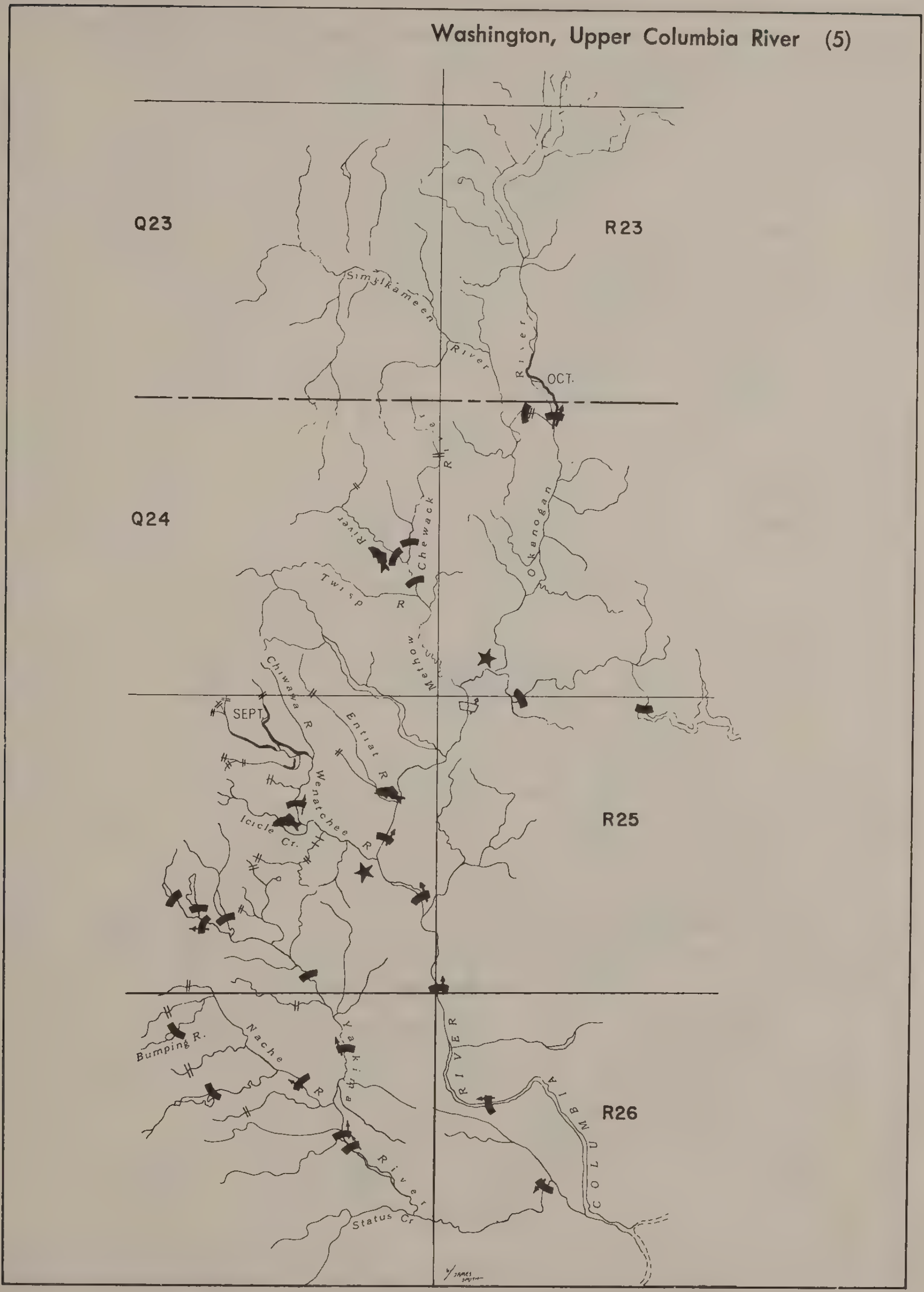
Washington, Upper Columbia River (5)
Q23
R23
Similkameen River
River
OCT.
Okanogan
R.
Q24
River
Chewack
Twisp R
Methow
Chiwawa R
SEPT.
Entiat R
Wenatchee R
Icicle Cr.
R25
Bumping R.
Nache R
Yakima River
Status Cr
RIVER
COLUMBIA
R26

Figure 18. Spawning grounds of chinook salmon on Upper Columbia River.

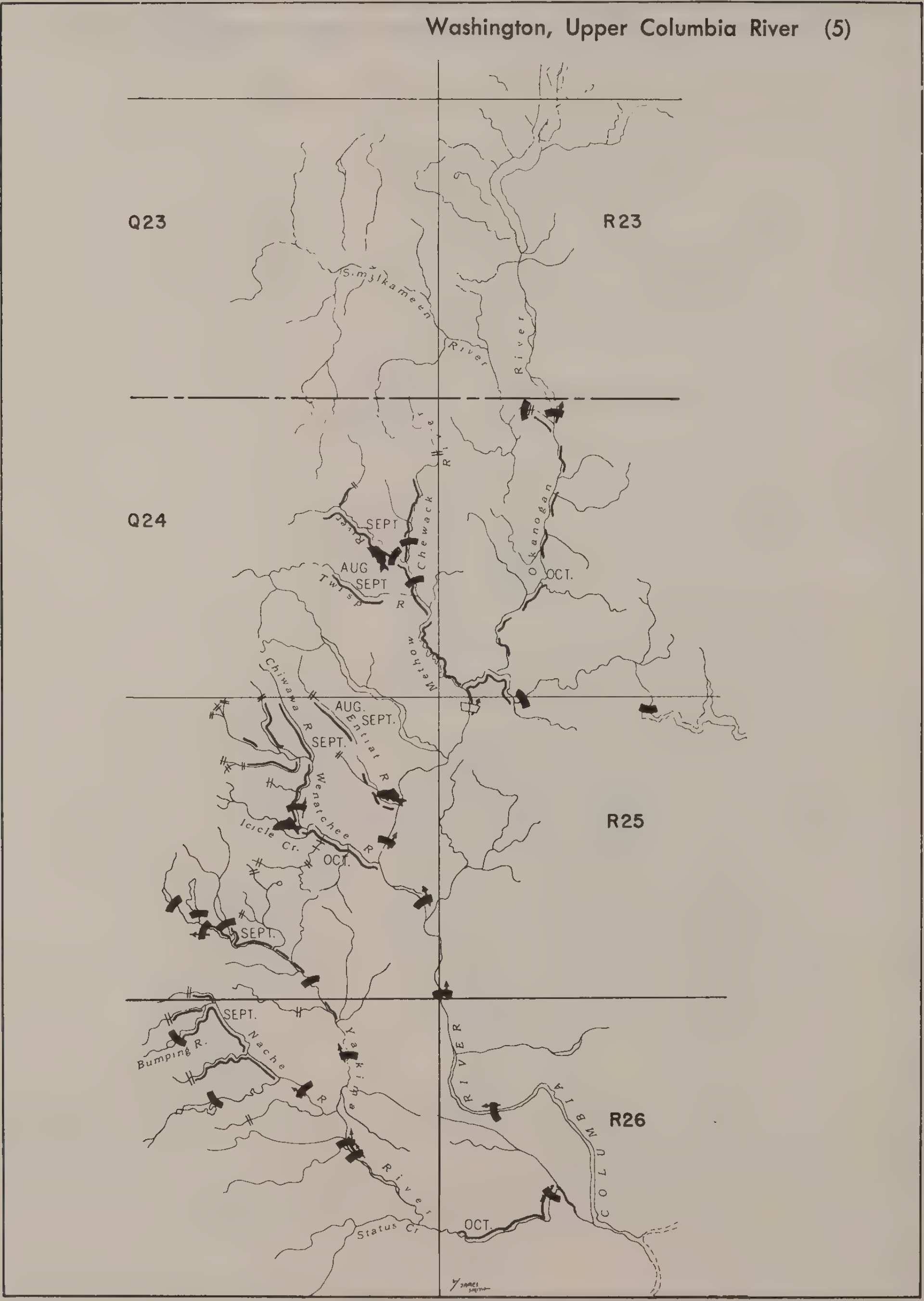
Washington, Upper Columbia River (5)
Q23
R23
Q24
R25
R26
S. Similkameen River
River
Okanogan
OCT.
Chewack R
Twisp R
AUG
SEPT
SEPT
Methow
Chiwawa R
SEPT.
AUG.
SEPT.
Entiat R
Wenatchee R
Icicle Cr.
OCT.
SEPT.
SEPT.
Bumping R.
Nache R
Yakima River
Status Cr
OCT.
RIVER
COLUMBIA

Figure 19. Spawning grounds of sockeye salmon on Upper Columbia River.

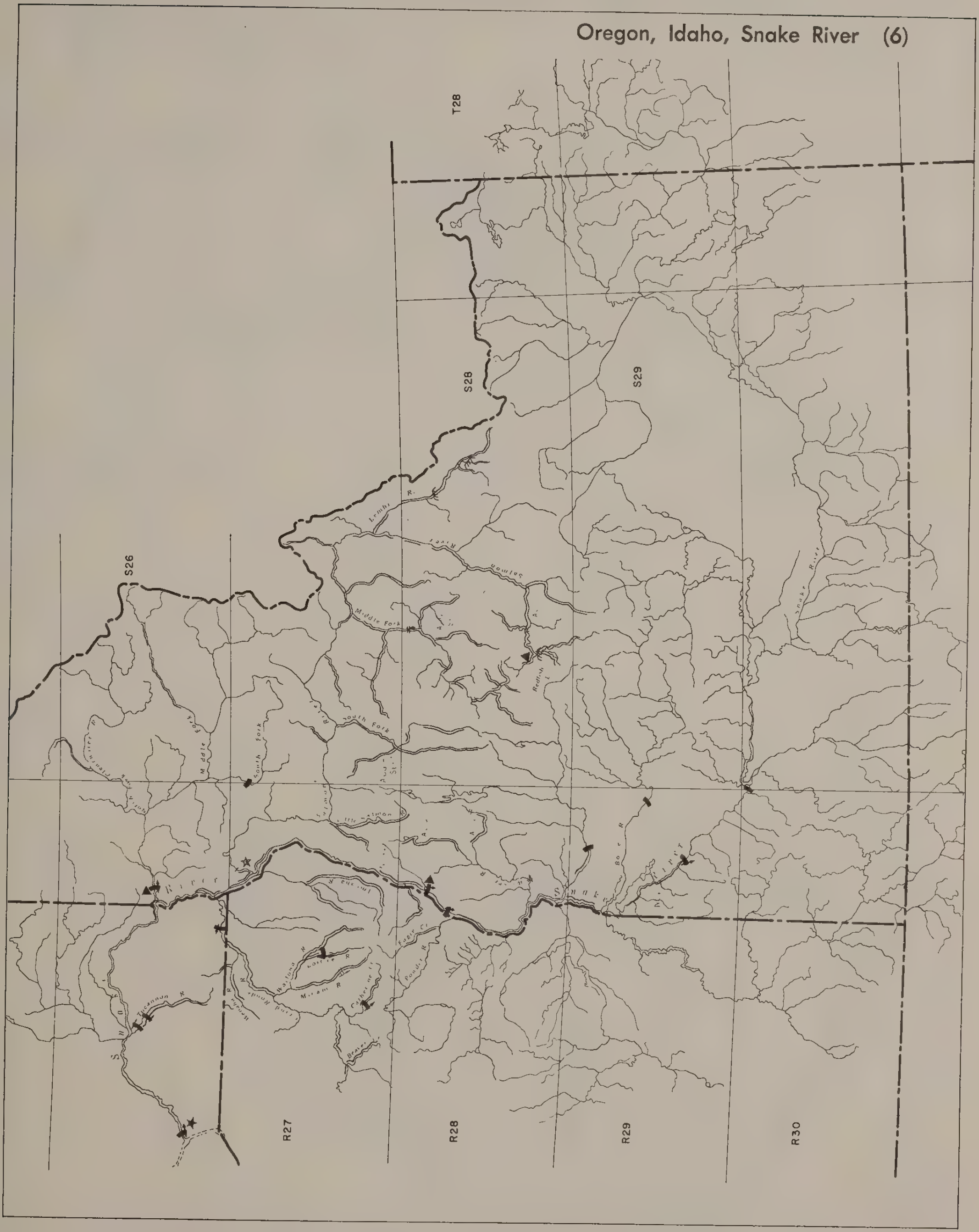
Oregon, Idaho, Snake River (6)
T28
S28
S29
S26
Lemhi R.
Salmon River
Middle Fork
Redfish L.
South Fork
Middle Fork
South Fork
Little Salmon R.
Snake River
Imnaha R.
Lostine R.
Wallowa R.
Minam R.
Grande Ronde R.
Catherine Cr.
Eagle Cr.
Powder R.
Tucannon R.
Boise R.
Payette R.
R27
R28
R29
R30

FIGURE 20. Spawning grounds of chinook salmon on Snake River.

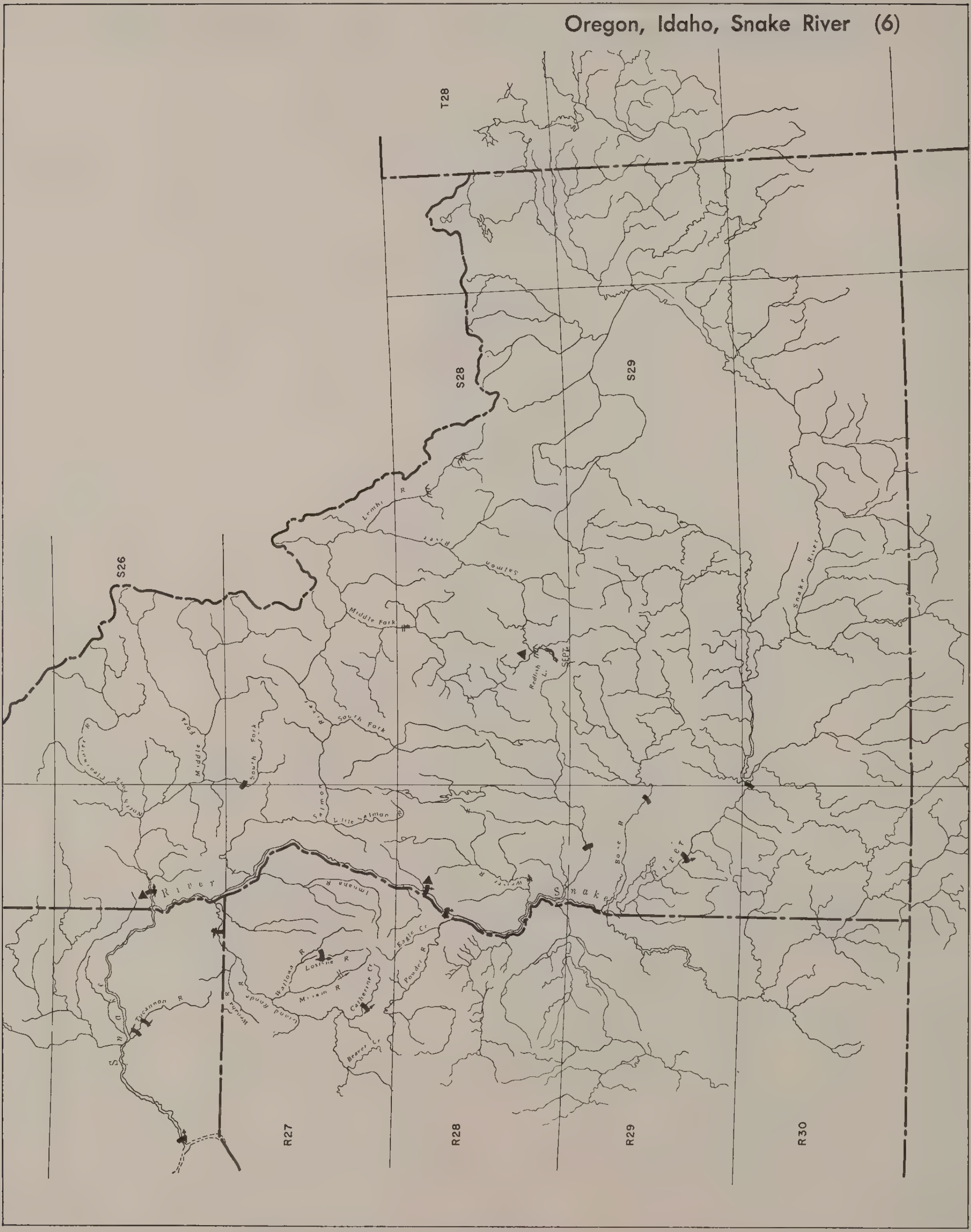
Oregon, Idaho, Snake River (6)
T28
S28
S29
S26
Lemhi R
Salmon River
Middle Fork
South Fork
Redfish L.
Snake River
Middle Fork
South Fork
Clearwater R
North Fork
Salmon R
Little Salmon R
Snake River
Weiser R
Boise R
Imnaha R
Eagle Cr
Powder R
Wallowa R
Lostine R
Minam R
Catherine Cr
Grande Ronde R
Wenaha R
Beaver Cr
Tucannon R
R27
R28
R29
R30

FIGURE 21. Spawning grounds of sockeye salmon on Snake River.

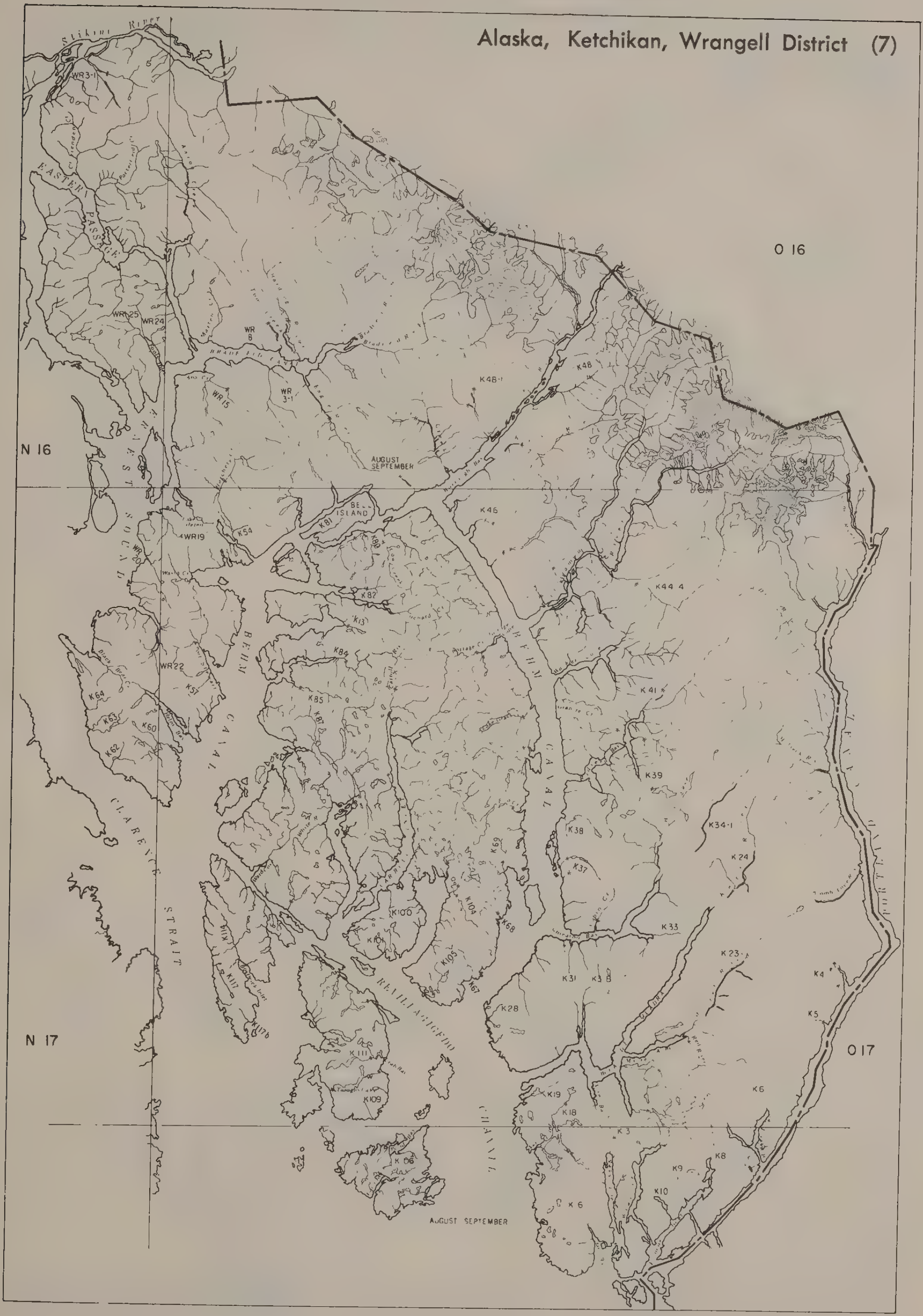
Alaska, Ketchikan, Wrangell District (7)
Stikine River
WR3-1
EASTERN PASSAGE
WR25
WR24
WR 8
WR 3-1
WR15
N 16
AUGUST SEPTEMBER
K48-1
K48
O 16
BELL ISLAND
K81
K54
WR19
K82
K13
K84
K85
K87
WR22
K57
K64
K63
K60
K62
BEHM CANAL
CLARENCE STRAIT
K46
K44 4
K41
K39
K38
K37
K34-1
K24
K33
K23
K31
K3 8
K4
K5
K28
K69
K104
K68
K105
K67
K100
K101
K116
K117
K111
K109
K108
REVILLAGIGEDO CHANNEL
K19
K18
K3
K9
K8
K10
K6
N 17
O 17
AUGUST SEPTEMBER

FIGURE 22. Spawning grounds of chinook salmon in Southeastern Alaska (Ketchikan-Wrangell).

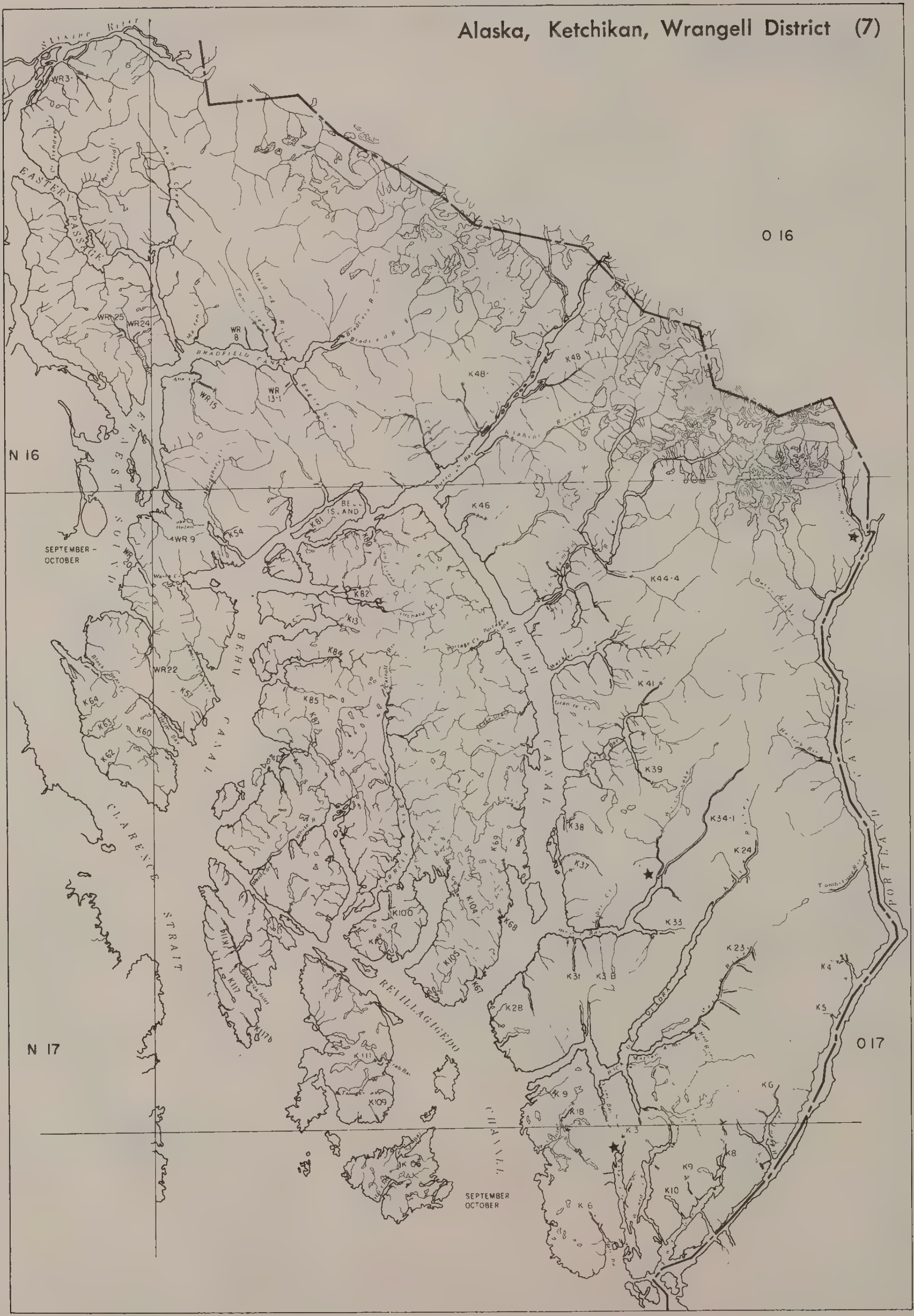
Alaska, Ketchikan, Wrangell District (7)
Stikine River
WR3
EASTERN PASSAGE
WR 25
WR24
WR 8
BRADFIELD CANAL
WR 13-1
WR15
ERNEST SOUND
N 16
O 16
K48
K48
K46
BELL ISLAND
K81
K54
WR 9
SEPTEMBER - OCTOBER
K82
K13
K84
K85
K44-4
K41
K39
K38
K37
K34-1
K24
K33
K23
K31
K28
BEHM CANAL
WR22
K57
K64
K63
K60
K62
CLARENCE STRAIT
K69
K104
K100
K105
K68
K67
K117
REVILLAGIGEDO CHANNEL
N 17
O 17
K111
K109
K4
K5
K6
K9
K18
K3
K8
K9
K10
K 6
SEPTEMBER OCTOBER
PORTLAND CANAL

Figure 23. Spawning grounds of chum salmon in Southeastern Alaska (Ketchikan-Wrangell).

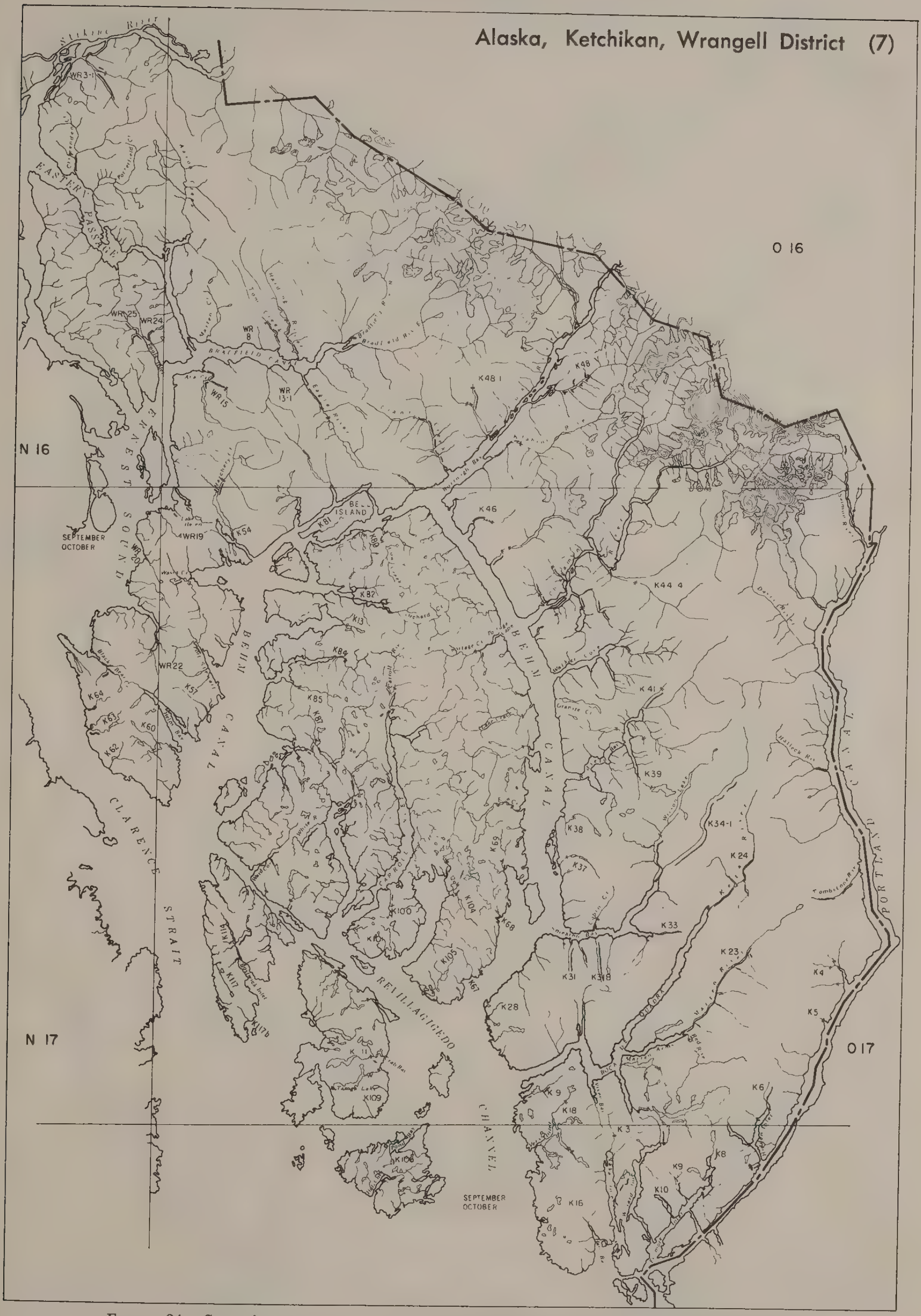
Alaska, Ketchikan, Wrangell District (7)
Stikine River
WR3-11
EASTERN PASSAGE
WR25
WR24
WR 8
BRADFIELD C.
WR15
WR 13-1
K48 1
K48
O 16
N 16
SEPTEMBER
OCTOBER
ERNEST SOUND
WR19
K54
K81
BELL ISLAND
K82
K13
K84
WR22
K51
K64
K63
K60
K62
K85
K87
BEHM CANAL
K46
K44 4
K41
K39
K38
K37
K34-1
K24
K69
K100
K104
K68
K33
K23
K4
K5
O 17
CLARENCE STRAIT
K114
K117
K31
K3 18
K105
K67
K28
N 17
REVILLAGIGEDO CHANNEL
K 11
K109
K108
K9
K18
K3
K8
K9
K10
K16
SEPTEMBER
OCTOBER
PORTLAND CANAL

FIGURE 24. Spawning grounds of coho salmon in Southeastern Alaska (Ketchikan-Wrangell).

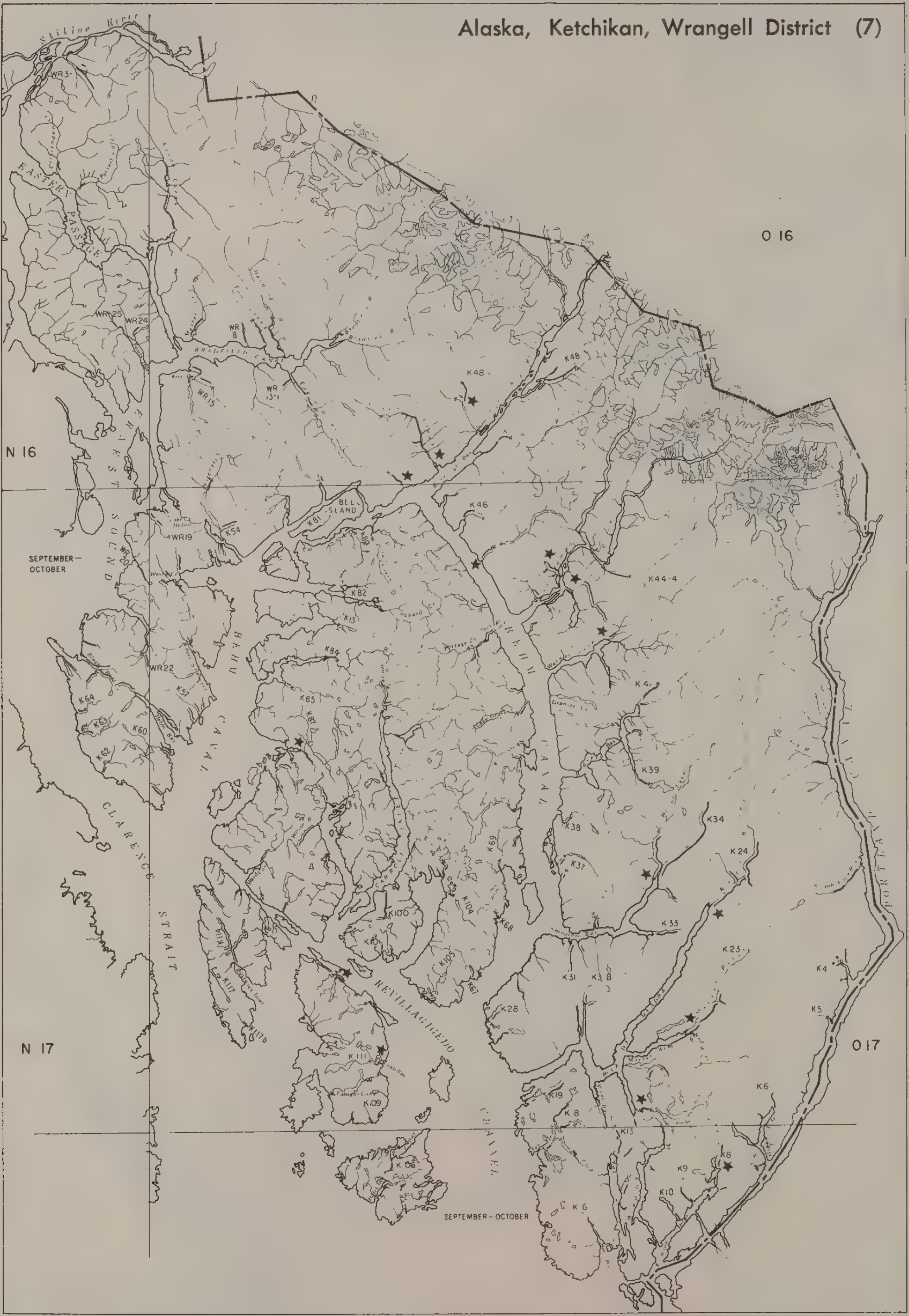
Alaska, Ketchikan, Wrangell District (7)
Stikine River
WR3
EASTERN PASSAGE
WR25
WR24
WR 8
WR 15
WR 13-1
K48
K48
O 16
N 16
ERNEST SOUND
BELL ISLAND
K81
K54
WR19
WR20
K46
SEPTEMBER— OCTOBER
K82
K13
K84
K44-4
BEHM CANAL
WR22
K57
K64
K63
K60
K62
K85
K87
K41
K39
CLARENCE STRAIT
K38
K34
K24
K37
K33
K23
K100
K104
K68
K105
K67
K4
K5
K31
K28
REVILLAGIGEDO CHANNEL
N 17
O 17
K111
K117
K19
K8
K6
K13
K8
K9
K10
K6
SEPTEMBER - OCTOBER

Figure 25. Spawning grounds of pink salmon in Southeastern Alaska (Ketchikan-Wrangell).

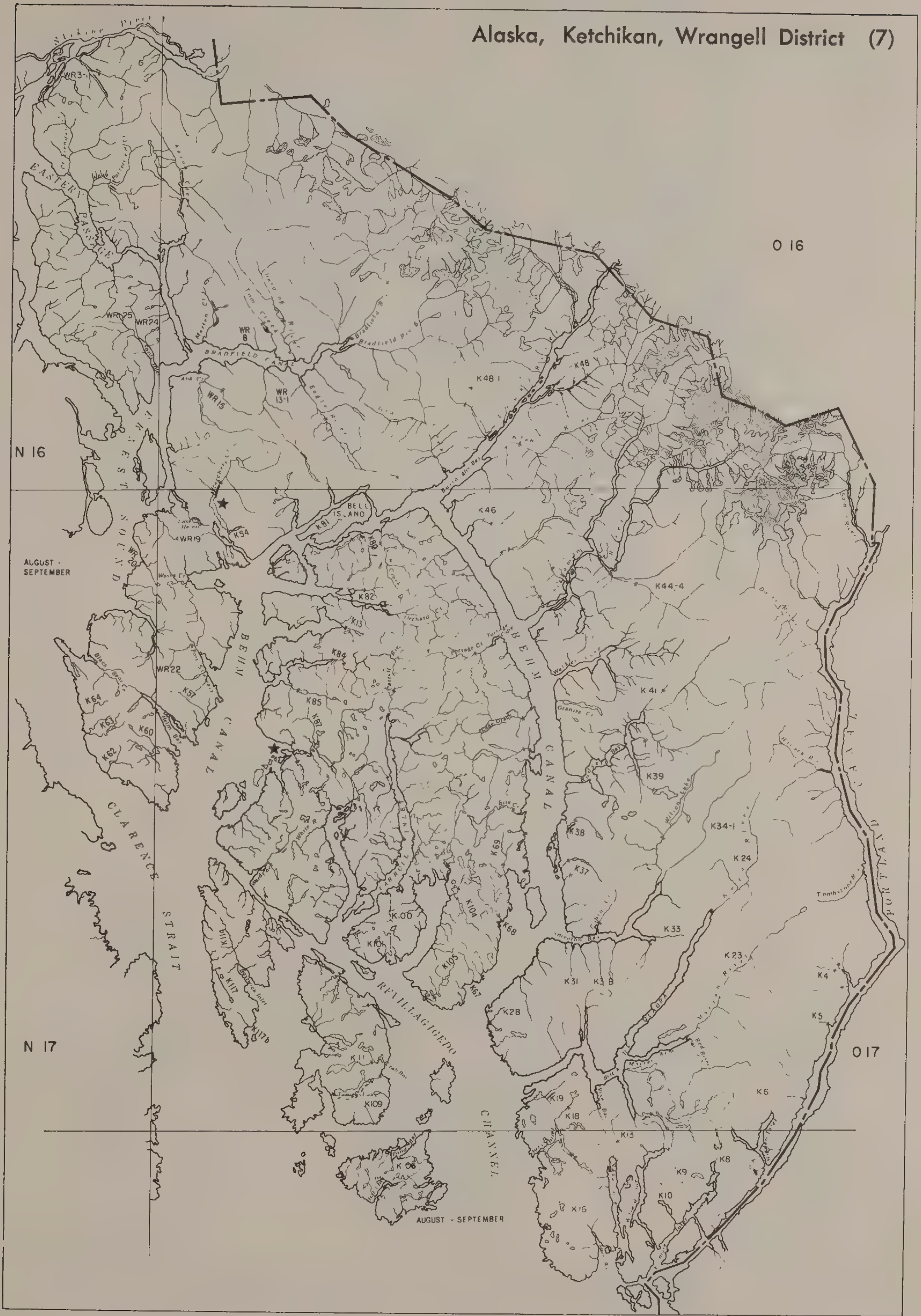
Alaska, Ketchikan, Wrangell District (7)
O 16
N 16
N 17
O 17
EASTERN PASSAGE
BRADFIELD CANAL
BELL ISLAND
BEHM CANAL
CLARENCE STRAIT
REVILLAGIGEDO CHANNEL
PORTLAND CANAL
AUGUST - SEPTEMBER
AUGUST - SEPTEMBER
WR3
WR25
WR24
WR 8
WR 13-1
WR15
WR19
WR22
K48 1
K48
K46
K44-4
K41
K39
K38
K37
K34-1
K24
K33
K23
K4
K5
K6
K31
K3 B
K28
K19
K18
K13
K8
K9
K10
K16
K54
K81
K82
K13
K84
K85
K53
K64
K63
K60
K62
K00
K101
K104
K105
K68
K67
K11
K109
K106
K117

Figure 26. Spawning grounds of sockeye salmon in Southeastern Alaska (Ketchikan-Wrangell).

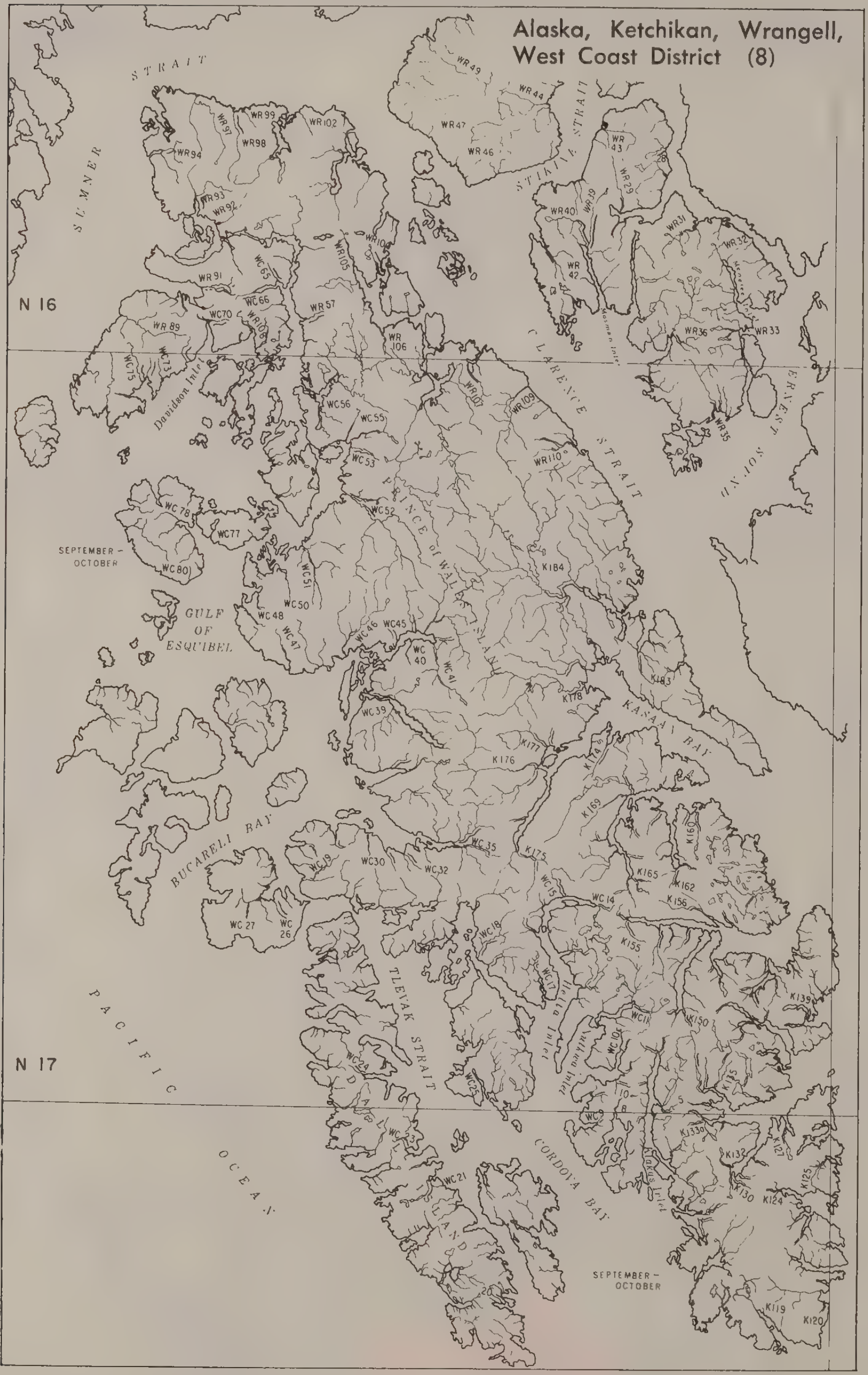
Alaska, Ketchikan, Wrangell, West Coast District (8)
SUMNER STRAIT
STIKINE STRAIT
CLARENCE STRAIT
ERNEST SOUND
PRINCE of WALES ISLAND
KASAAN BAY
GULF OF ESQUIBEL
BUCARELI BAY
TLEVAK STRAIT
CORDOVA BAY
DALL ISLAND
PACIFIC OCEAN
Davidson Inlet
Helm Inlet
Kaigani Inlet
N 16
N 17
SEPTEMBER – OCTOBER
SEPTEMBER – OCTOBER
WR 49
WR 44
WR 47
WR 46
WR 43
WR 29
WR 19
WR 40
WR 42
WR 31
WR 32
WR 36
WR 33
WR 35
WR 99
WR 97
WR 98
WR 102
WR 94
WR 93
WR 92
WR 104
WR 105
WR 91
WR 57
WR 89
WR 106
WR 107
WR 109
WR 110
WC 65
WC 66
WC 70
WC 75
WC 73
WC 56
WC 55
WC 53
WC 52
WC 78
WC 77
WC 80
WC 51
WC 50
WC 48
WC 47
WC 46
WC 45
WC 40
WC 41
WC 39
WC 35
WC 19
WC 30
WC 32
WC 27
WC 26
WC 15
WC 14
WC 18
WC 17
WC 11
WC 10
WC 9
WC 24
WC 25
WC 23
WC 21
K 184
K 183
K 178
K 177
K 176
K 174
K 169
K 175
K 160
K 165
K 162
K 156
K 155
K 150
K 139
K 135
K 133
K 132
K 127
K 125
K 130
K 124
K 119
K 120

Figure 27. Spawning grounds of chum salmon in Southeastern Alaska (Ketchikan-Wrangell-West Coast).

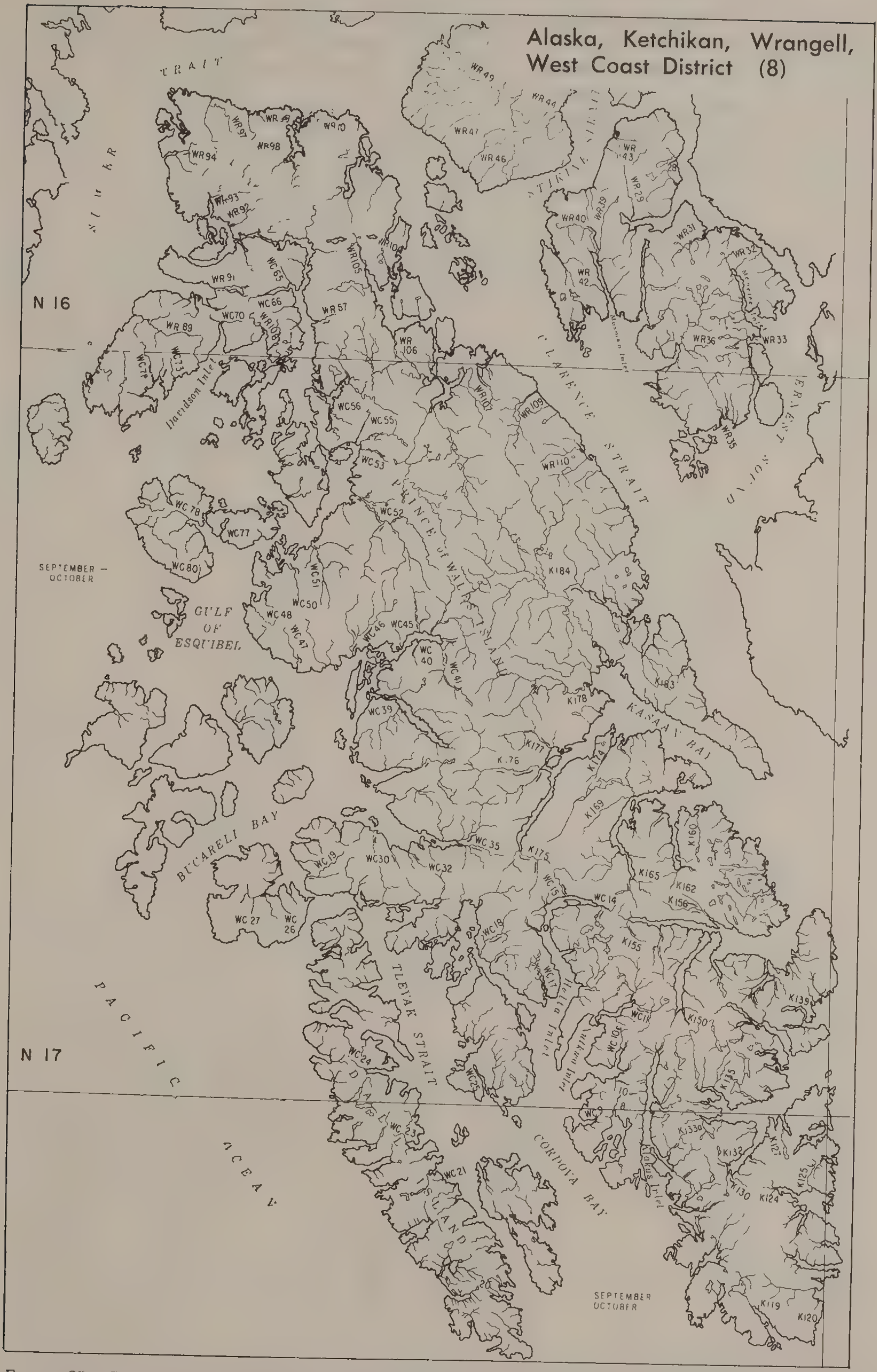
Alaska, Ketchikan, Wrangell, West Coast District (8)
TRAIT
SUMNER
STIKINE STRAIT
CLARENCE STRAIT
ERNEST SOUND
PRINCE OF WALES ISLAND
KASAAN BAY
GULF OF ESQUIBEL
Davidson Inlet
BUCARELI BAY
TLEVAK STRAIT
CORDOVA BAY
DALL ISLAND
PACIFIC OCEAN
Hetta Inlet
Moira Inlet
Kaigani Inlet
Niblack Inlet
N 16
N 17
SEPTEMBER — OCTOBER
SEPTEMBER OCTOBER
WR 49
WR 44
WR 47
WR 46
WR 43
WR 29
WR 39
WR 40
WR 42
WR 31
WR 32
WR 36
WR 33
WR 35
WR 97
WR 98
WR 10
WR 94
WR 93
WR 92
WR 104
WR 105
WR 91
WC 65
WC 66
WC 70
WR 89
WC 71
WC 73
WR 57
WR 106
WR 107
WR 109
WR 110
WC 56
WC 55
WC 53
WC 52
WC 78
WC 77
WC 80
WC 51
WC 50
WC 48
WC 47
WC 46
WC 45
WC 40
WC 41
WC 39
K 184
K 183
K 178
K 177
K 176
K 174
K 159
K 160
K 165
K 162
K 156
K 175
WC 35
WC 30
WC 32
WC 19
WC 27
WC 26
WC 15
WC 14
WC 18
K 155
WC 17
WC 11
WC 10
K 150
K 139
K 135
WC 24
WC 25
WC 9
WC 23
K 133
K 132
K 127
K 125
K 130
K 124
WC 21
K 119
K 120

Figure 28. Spawning grounds of coho salmon in Southeastern Alaska (Ketchikan-Wrangell-West Coast).

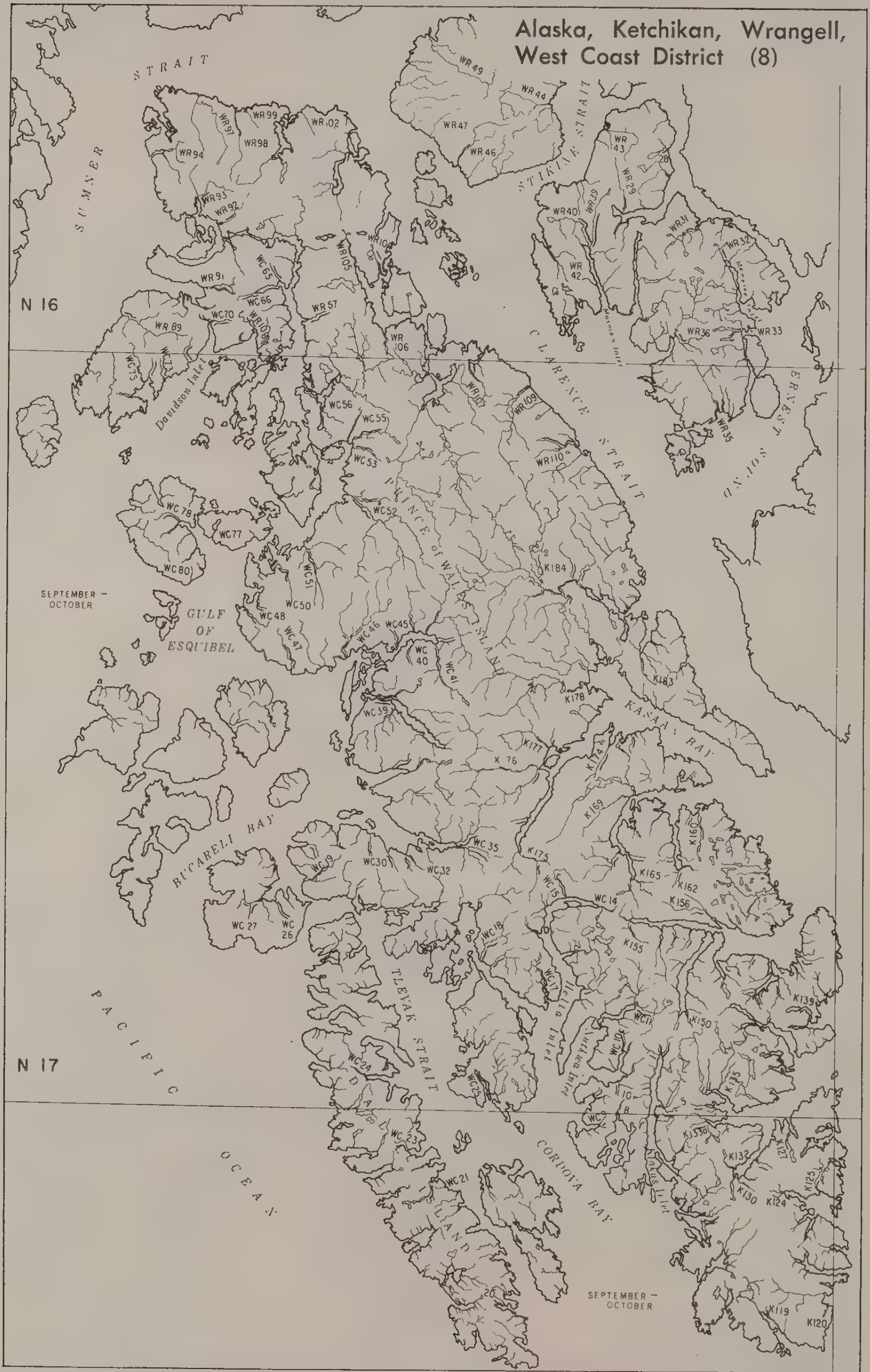
Alaska, Ketchikan, Wrangell, West Coast District (8)
SUMNER STRAIT
STIKINE STRAIT
CLARENCE STRAIT
ERNEST SOUND
Davidson Inlet
GULF OF ESQUIBEL
PRINCE of WALES ISLAND
KASAAN BAY
BUCARELI BAY
TLEVAK STRAIT
DALL ISLAND
CORDOVA BAY
PACIFIC OCEAN
SEPTEMBER – OCTOBER
SEPTEMBER – OCTOBER
N 16
N 17
WR49
WR44
WR47
WR46
WR43
WR29
28
WR39
WR40
WR42
WR31
WR32
WR36
WR33
WR35
WR99
WR97
WR98
WR102
WR94
WR93
WR92
WR91
WR104
WR105
WC65
WC66
WC70
WR108
WR57
WR89
WC73
WR106
WR107
WR109
WR110
WC56
WC55
WC53
WC52
WC78
WC77
WC80
WC51
WC50
WC48
WC47
WC46
WC45
WC40
WC41
WC39
K184
K183
K178
K177
K76
K174
K169
K175
K160
K165
K162
K156
WC35
WC30
WC32
WC19
WC27
WC26
WC15
WC14
WC18
K155
WC17
K150
WC11
WC10
K139
K135
WC24
WC25
WC23
WC21
WC9
K133
K132
K127
K130
K124
K125
K119
K120
10
8
5
20
Hetta Inlet
Sukkwan Inlet
Moira Sound

Figure 29. Spawning grounds of pink salmon in Southeastern Alaska (Ketchikan-Wrangell-West Coast).

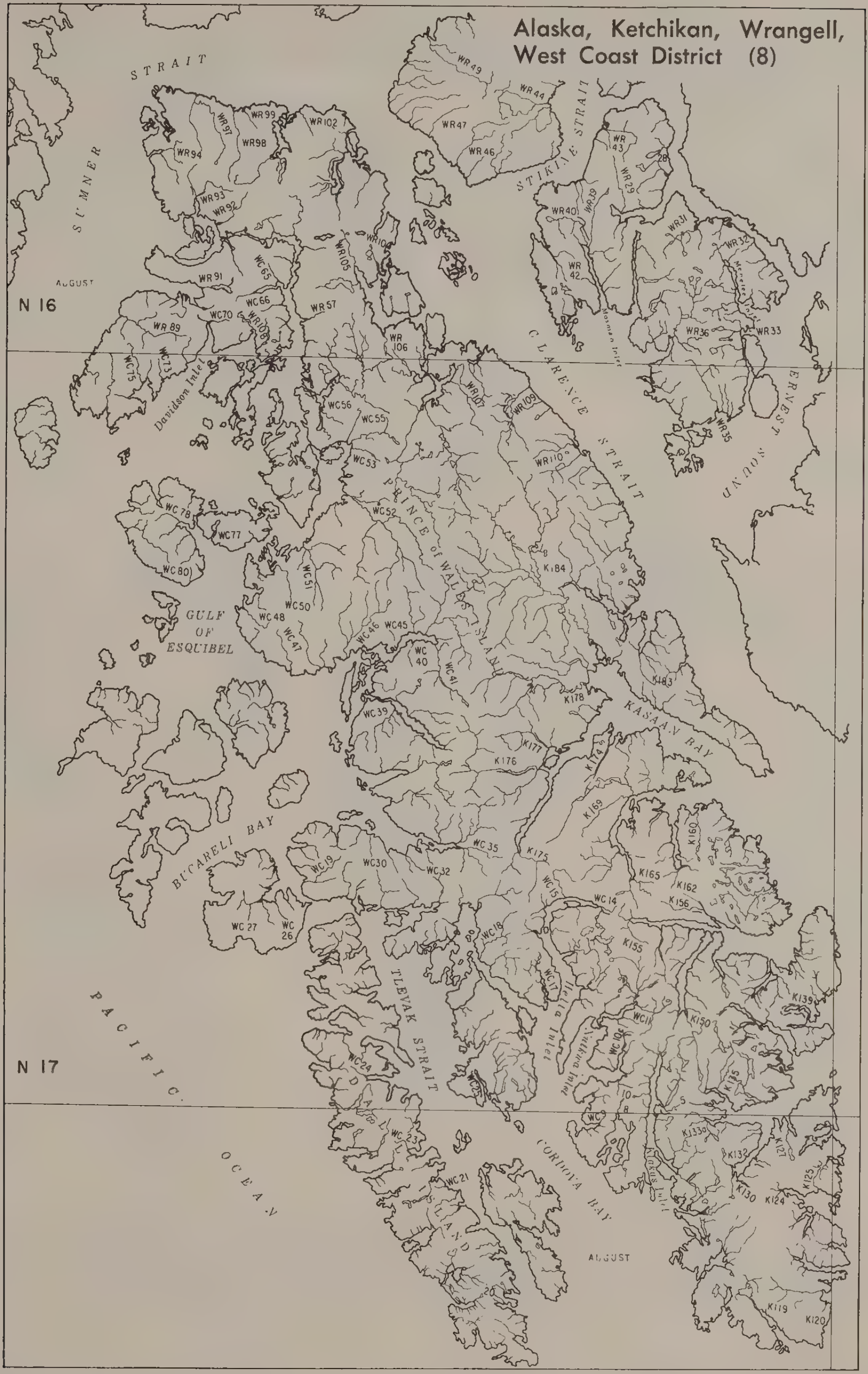
Alaska, Ketchikan, Wrangell, West Coast District (8)
STRAIT
SUMNER
N 16
AUGUST
WR 99
WR 97
WR 98
WR 102
WR 94
WR 93
WR 92
WR 91
WC 65
WR 105
WR 104
WC 66
WC 70
WR 108
WR 57
WR 89
WC 75
WC 73
Davidson Inlet
WR 106
WC 56
WC 55
WC 53
WC 52
WC 78
WC 77
WC 80
WC 51
WC 50
WC 48
WC 47
WC 46
WC 45
GULF OF ESQUIBEL
WC 40
WC 41
WC 39
WR 49
WR 44
WR 47
WR 46
STIKINE STRAIT
WR 43
28
WR 29
WR 39
WR 40
WR 42
Nosman Inlet
WR 31
WR 32
Menefee Inlet
WR 36
WR 33
WR 35
ERNEST SOUND
CLARENCE STRAIT
WR 107
WR 109
WR 110
PRINCE of WALES ISLAND
K 184
K 183
K 178
KASAAN BAY
K 177
K 176
K 174
K 169
K 160
K 165
K 162
K 156
WC 35
K 175
WC 32
WC 30
WC 19
BUCARELI BAY
WC 27
WC 26
WC 15
WC 14
WC 18
K 155
WC 17
Hetta Inlet
WC 11
WC 10
Nutkwa Inlet
K 150
K 139
K 135
10
8
5
WC 9
TLEVAK STRAIT
PACIFIC OCEAN
N 17
WC 24
WC 23
DALL ISLAND
WC 21
CORDOVA BAY
K 133
K 132
K 127
K 125
K 130
K 124
Kassa Inlet
AUGUST
K 119
K 120

Figure 30. Spawning grounds of sockeye salmon in Southeastern Alaska (Ketchikan-Wrangell-West Coast).

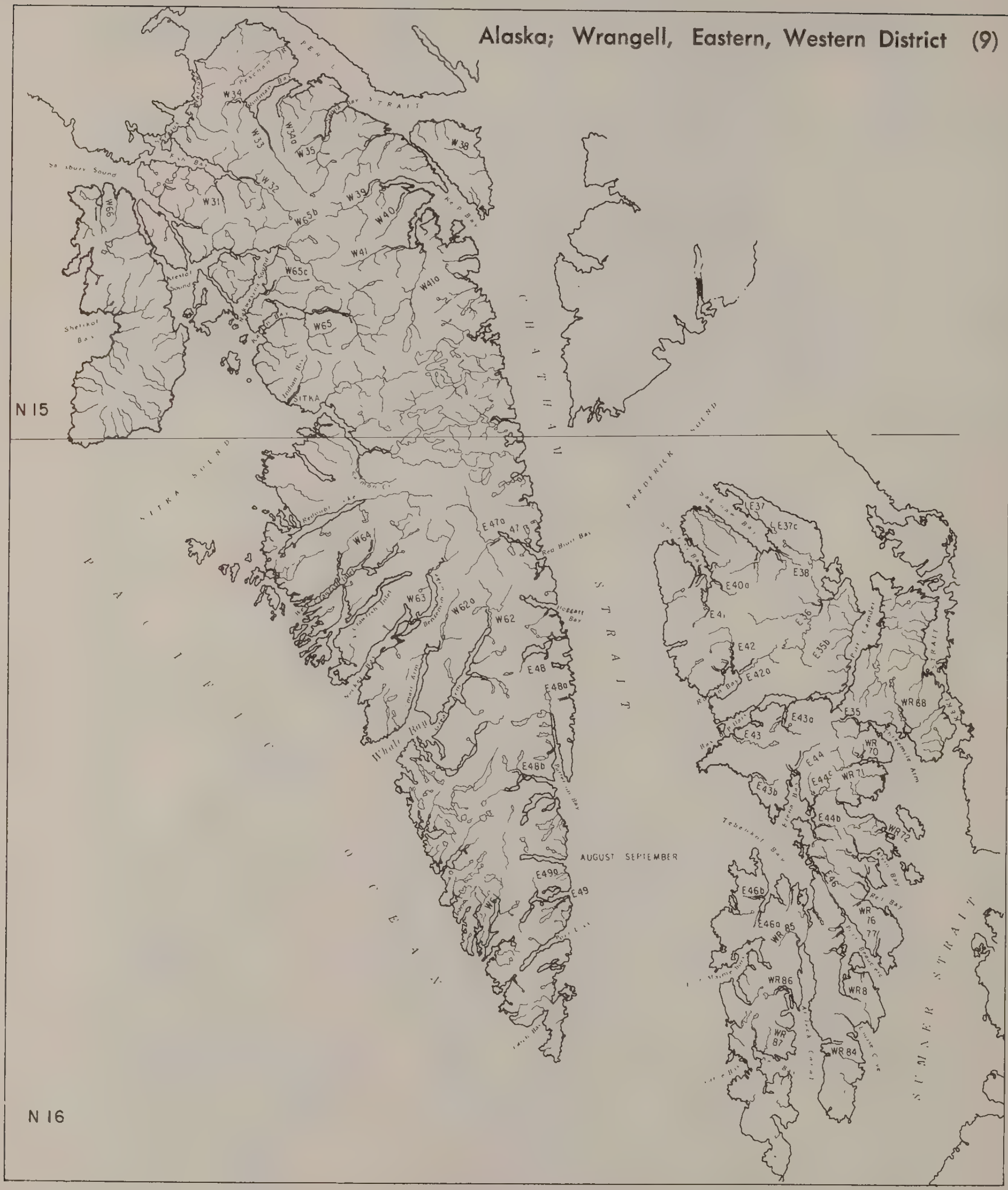
Alaska; Wrangell, Eastern, Western District (9)
N 15
N 16
W34
W33
W34a
W35
W38
W32
W31
W66
W39
W40
W65b
W41
W65c
W41a
W65
SITKA
Peschan
Rodman Bay
STRAIT
Fish Bay
Sound
Krestof Sound
Nakwasina Sound
Katlian Bay
Shelikof Bay
Indian Riv
SITKA SOUND
CHATHAM
Salmon Cr
Redoubt Lake
W64
W63
W62a
W62
Whale Bay
Crawfish Inlet
E47a
47
Red Bluff Bay
Hoggatt Bay
E48
E48a
E48b
AUGUST SEPTEMBER
E49a
E49
STRAIT
FREDERICK SOUND
PACIFIC OCEAN
E37
E37c
E38
E40a
E41
E36
E35b
E42
E42a
Port Camden
WR 88
E35
E43a
E43
E44
WR 70
WR 71
E44c
E43b
E44b
WR 72
Tebenkof Bay
E46b
E46
E46a
WR 85
WR 76
77
WR 86
WR 8
WR 87
WR 84
SUMNER STRAIT
KEKU STRAIT

FIGURE 31. Spawning grounds of chum salmon in Southeastern Alaska (Wrangell-Eastern-Western).

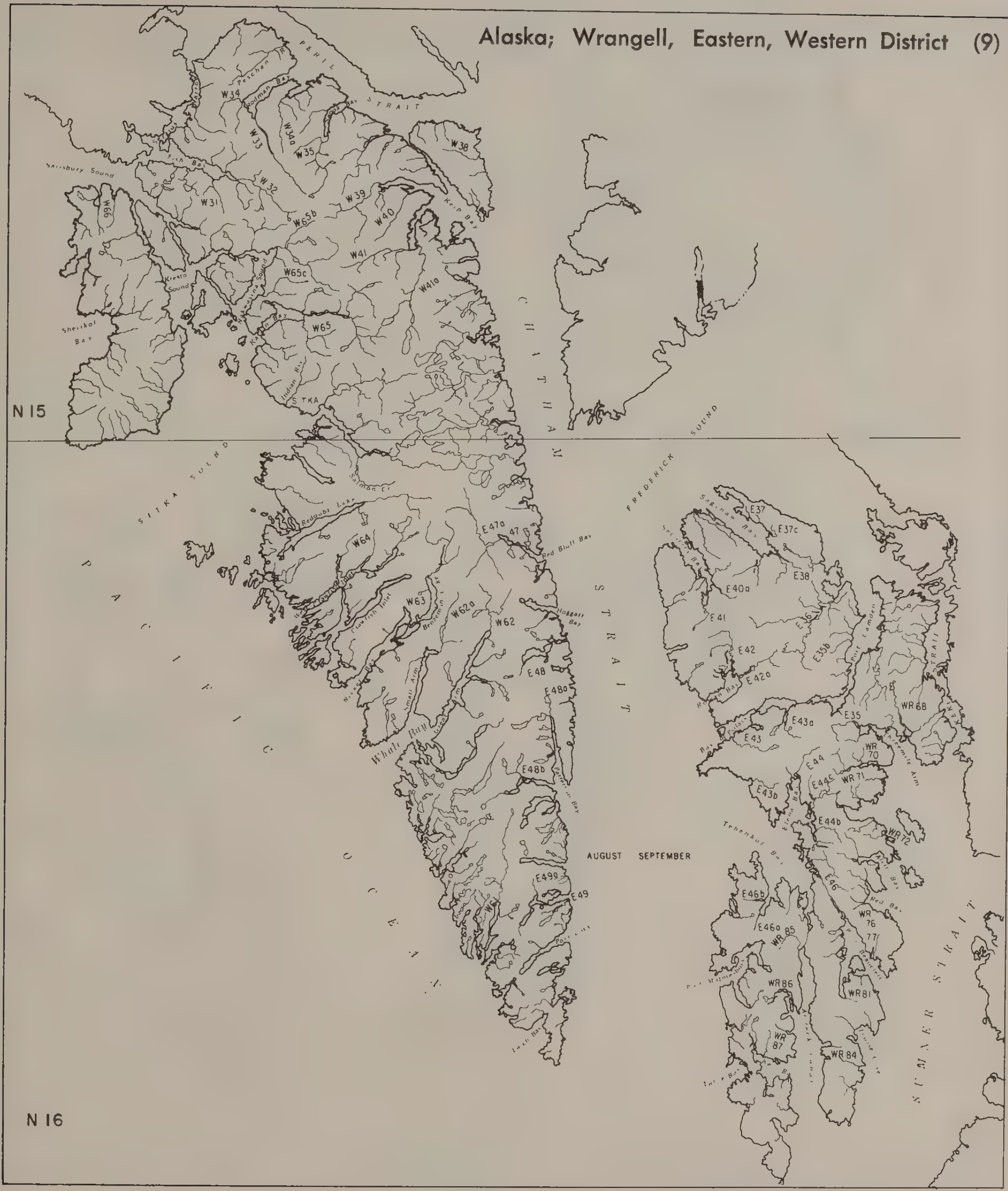
Alaska; Wrangell, Eastern, Western District (9)
N 15
N 16
PERIL STRAIT
Peschan R.
Salisbury Sound
Fish Bay
Kresta Sound
Sherikof Bay
Indian Riv.
SITKA
SITKA SOUND
Salmon Cr.
Redoubt Lake
Whale Bay
Small Arm
Kelp Bay
CHATHAM
STRAIT
FREDERICK SOUND
Red Bluff Bay
Saginaw Bay
Red Bay
Port Camden
Tebenkof Bay
SUMNER STRAIT
PACIFIC OCEAN
AUGUST SEPTEMBER
W31
W32
W33
W34
W34a
W35
W38
W39
W40
W41
W41a
W62
W62a
W63
W64
W65
W65b
W65c
W66
E35
E35b
E36
E37
E37c
E38
E40a
E41
E42
E42a
E43
E43a
E43b
E44
E44b
E44c
E46
E46a
E46b
E47a
47
E48
E48a
E48b
E49
E49a
WR 68
WR 70
WR 71
WR 72
WR 76
77
WR 81
WR 84
WR 85
WR 86
WR 87

Figure 32. Spawning grounds of coho salmon in Southeastern Alaska (Wrangell-Eastern-Western).

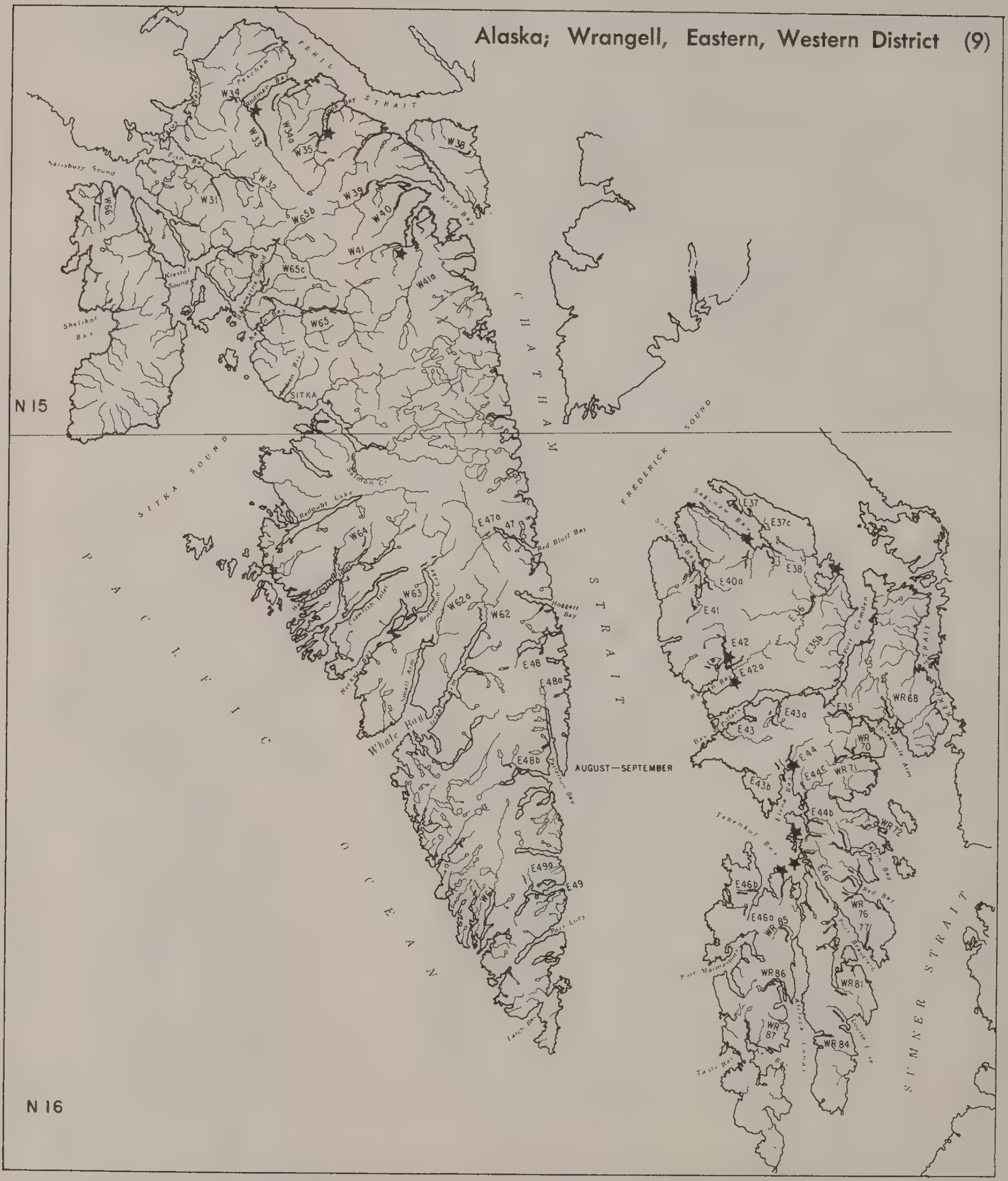
Alaska; Wrangell, Eastern, Western District (9)
N 15
N 16
PERIL STRAIT
Peschan R
Rodman Bay
Fish Bay
Salisbury Sound
Krestof Sound
Nakwasina Sound
Katlian Bay
Indian Riv
SITKA
Shelikof Bay
Kelp Bay
W34
W33
W34a
W35
W38
W32
W31
W39
W40
W66
W65b
W65c
W41
W41a
W65
CHATHAM STRAIT
FREDERICK SOUND
SITKA SOUND
PACIFIC OCEAN
Salmon Cr
Redoubt Lake
W64
Crawfish Inlet
W63
Benzeman Lake
W62a
W62
E47a
47
Red Bluff Bay
Hoggatt Bay
E48
E48a
Necker Bay
Small Arm
Whale Bay
E48b
Patterson Bay
AUGUST—SEPTEMBER
E49a
E49
Port Lucy
Larch Bay
Saginaw Bay
Security Bay
E37
E37c
E38
E40a
E41
E36
E35b
Port Camden
E42
E42a
Rowan Bay
Bay of Pillars
E43
E43a
E35
WR68
KEKU STRAIT
Threemile Arm
WR 70
E44
E44c
WR71
E43b
Elena Bay
Tebenkof Bay
E44b
WR72
Alvin Bay
E46
E46b
Red Bay
WR 76
77
E46a
WR 85
Port Protection
Port Malmesbury
WR86
WR81
Affleck Canal
WR 87
WR 84
Louise Cove
Table Bay
SUMNER STRAIT

FIGURE 33. Spawning grounds of pink salmon in Southeastern Alaska (Wrangell-Eastern-Western).

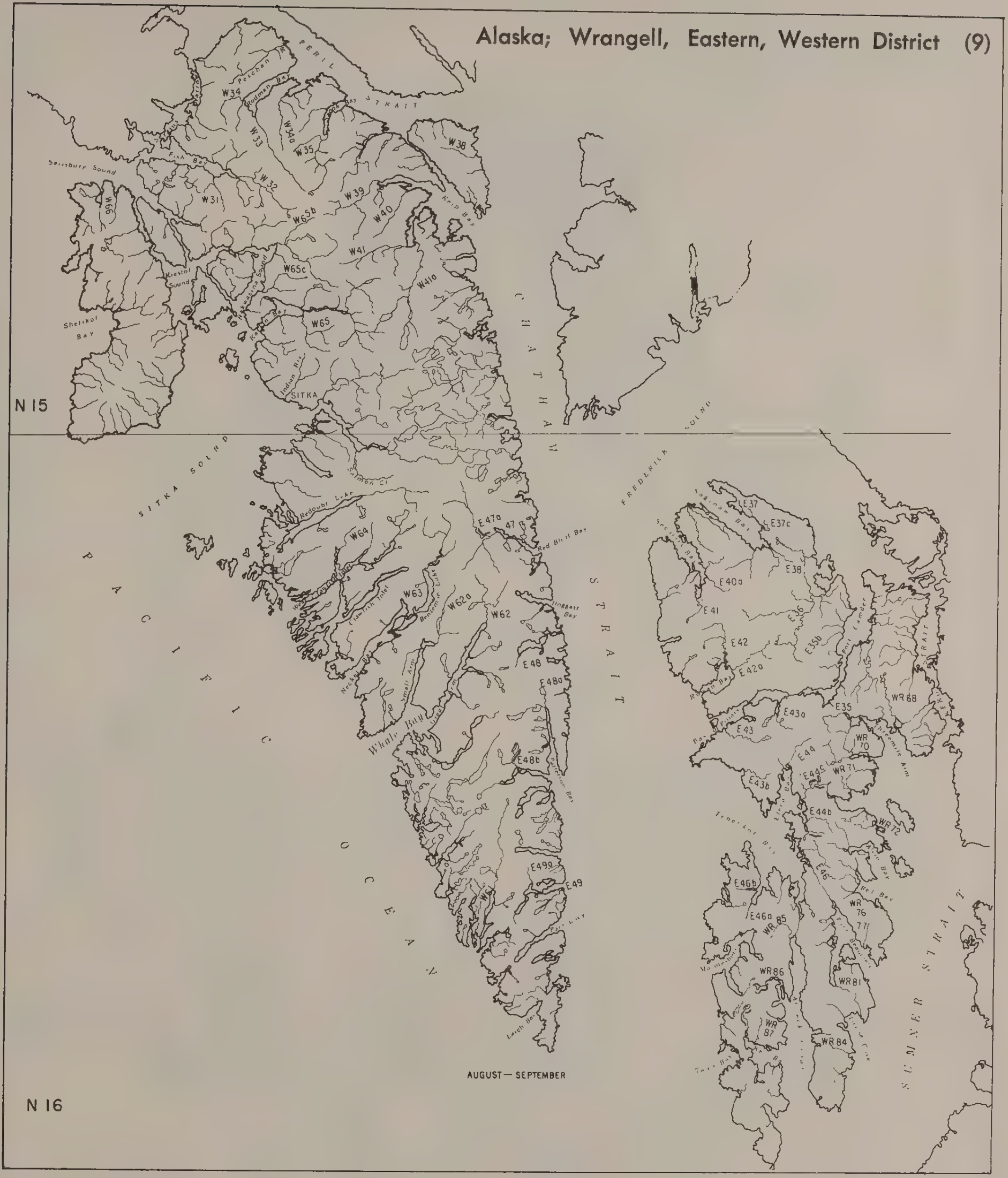
Alaska; Wrangell, Eastern, Western District (9)
PERIL STRAIT
Peschan R
Rodman Bay
W34
W33
W34a
W35
W38
Fish Bay
Salisbury Sound
W32
W31
W66
W65b
W39
W40
Kelp Bay
W41
W65c
Kiestol Sound
Nakwasina Sound
W41a
W65
Shelikof Bay
Katlian Bay
Indian Riv
SITKA
N 15
CHATHAM STRAIT
FREDERICK SOUND
SITKA SOUND
Salmon Cr
Redoubt Lake
W64
E47a
47
Red Bluff Bay
Crawfish Inlet
W63
Benzeman Lake
W62a
W62
Hoggatt Bay
Necker Bay
Small Arm
E48
E48a
Whale Bay
E48b
Patterson Bay
E49a
E49
W61
Port Lucy
Larch Bay
PACIFIC OCEAN
AUGUST — SEPTEMBER
N 16
Saginaw Bay
E37
E37c
Security Bay
E38
E40a
E41
E36
E42
E35b
Port Camden
E42a
Rowan Bay
STRAIT
WR 68
KEKU
E35
Bay of Pillars
E43
E43a
WR 70
Threemile Arm
E44
E44c
WR 71
E43b
Tebenkof Bay
E44b
WR 72
Alvin Bay
E46
E46b
Rel Bay
WR 76
77
E46a
WR 85
Port Beauclerc
Malmesbury
WR 86
WR 81
WR 87
WR 84
Affleck Canal
Little Cove
Toss Bay
SUMNER STRAIT

Figure 34. Spawning grounds of sockeye salmon in Southeastern Alaska (Wrangell-Eastern-Western).

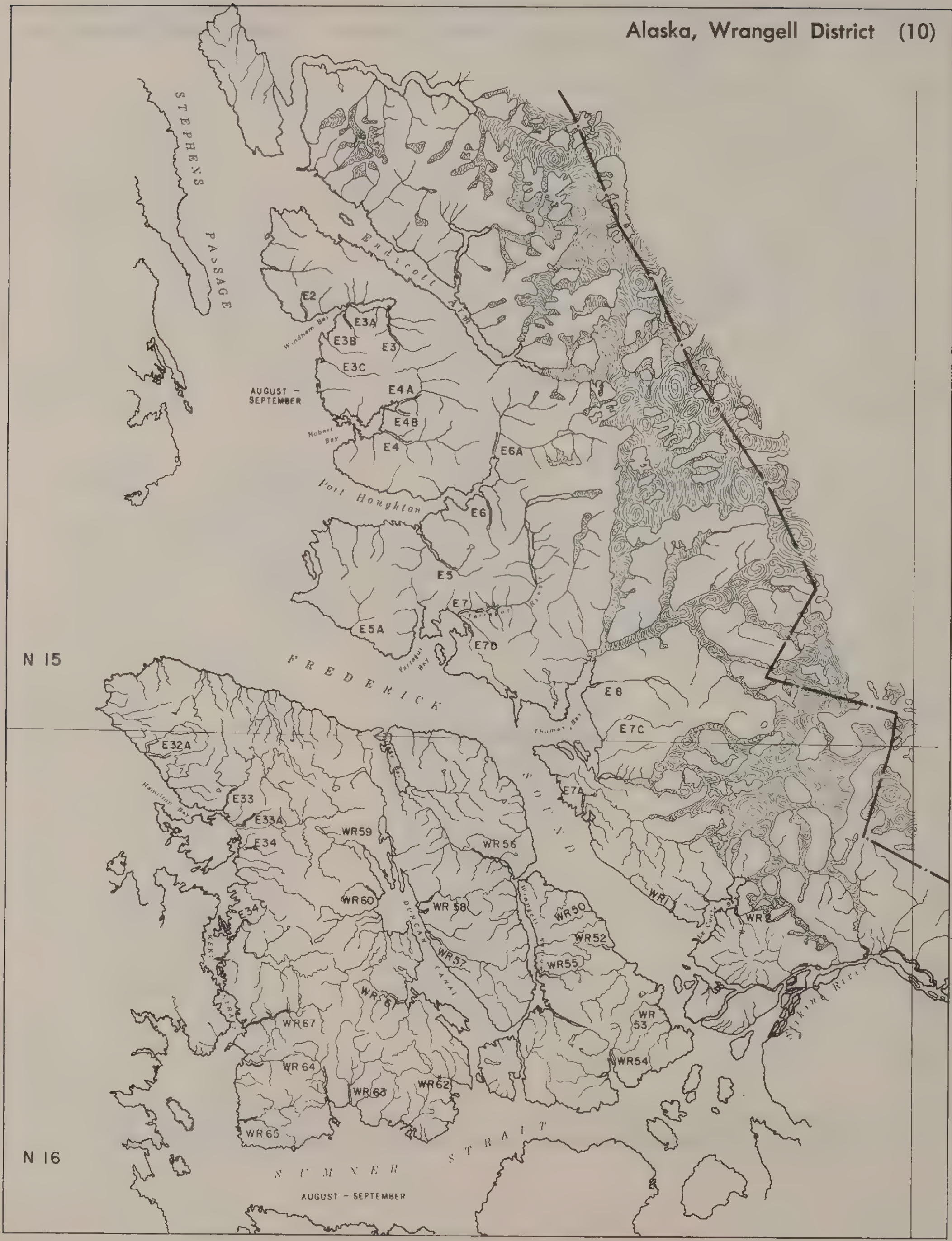
Alaska, Wrangell District (10)
STEPHENS PASSAGE
Endicott Arm
E2
E3A
E3B
E3
E3C
Windham Bay
AUGUST - SEPTEMBER
E4A
E4B
E4
Hobart Bay
E6A
Port Houghton
E6
E5
E7
Farragut River
E5A
E7D
Farragut Bay
N 15
FREDERICK SOUND
E8
Thomas Bay
E7C
E7A
E32A
Hamilton Bay
E33
E33A
E34
WR59
WR56
WR60
WR 58
E34
DUNCAN CANAL
WR57
Wrangell Narrows
WR50
WR52
WR55
WR1
Le Conte Bay
WR2
Stikine River
WR61
WR67
WR 53
WR54
WR 64
WR63
WR62
WR65
N 16
SUMNER STRAIT
AUGUST - SEPTEMBER

Figure 35. Spawning grounds of chum salmon in Southeastern Alaska (Wrangell).

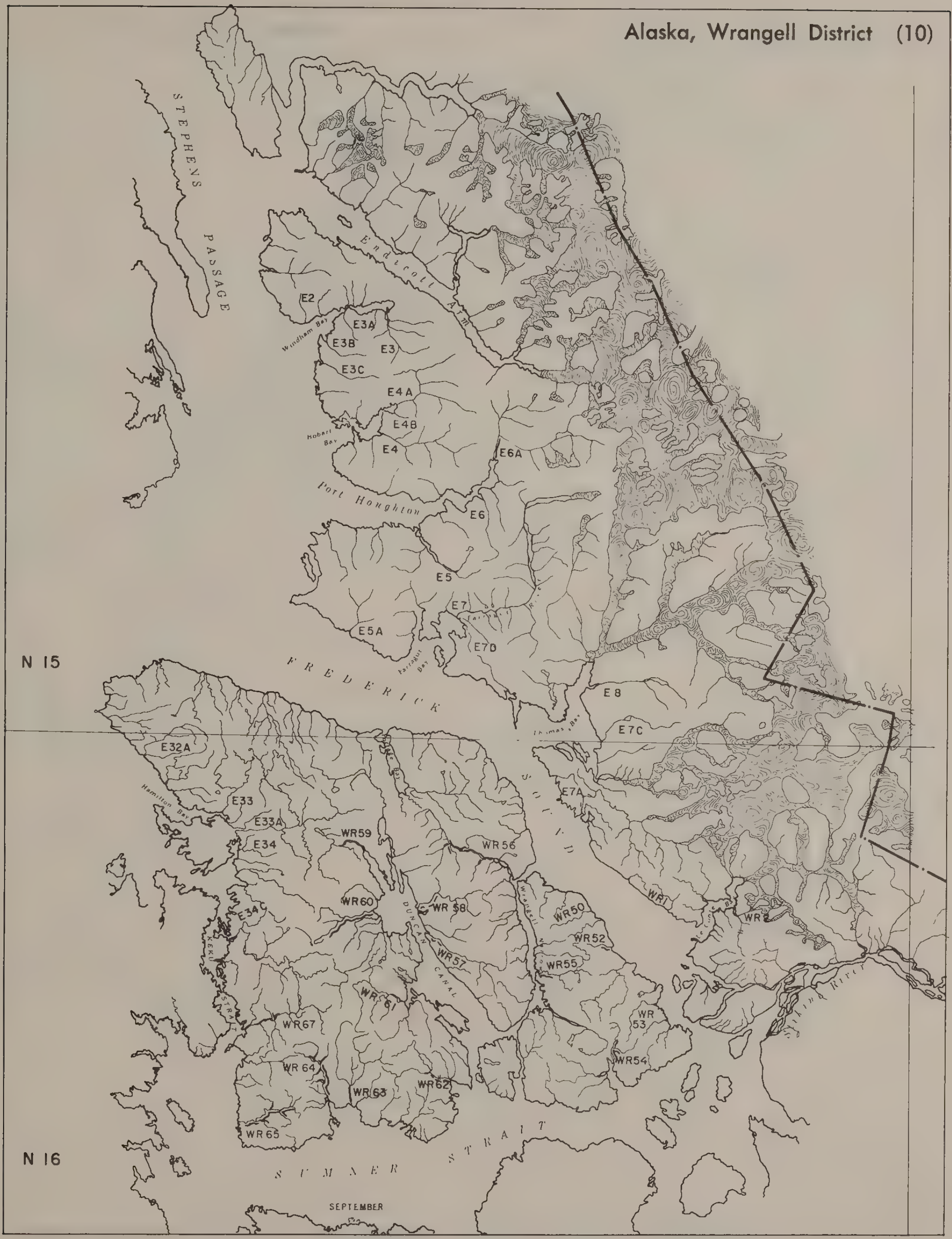
Alaska, Wrangell District (10)
STEPHENS PASSAGE
Endicott Arm
Windham Bay
Hobart Bay
Port Houghton
Farragut Bay
FREDERICK SOUND
Thomas Bay
Hamilton Bay
KEKU STRAIT
DUNCAN CANAL
Wrangell Narrows
Stikine River
SUMNER STRAIT
N 15
N 16
E2
E3A
E3B
E3
E3C
E4A
E4B
E4
E6A
E6
E5
E7
E5A
E7D
E8
E7C
E7A
E32A
E33
E33A
E34
E34C
WR59
WR56
WR60
WR 58
WR50
WR52
WR57
WR55
WR1
WR2
WR 61
WR67
WR 53
WR54
WR 64
WR63
WR62
WR 65
SEPTEMBER

FIGURE 36. Spawning grounds of coho salmon in Southeastern Alaska (Wrangell).

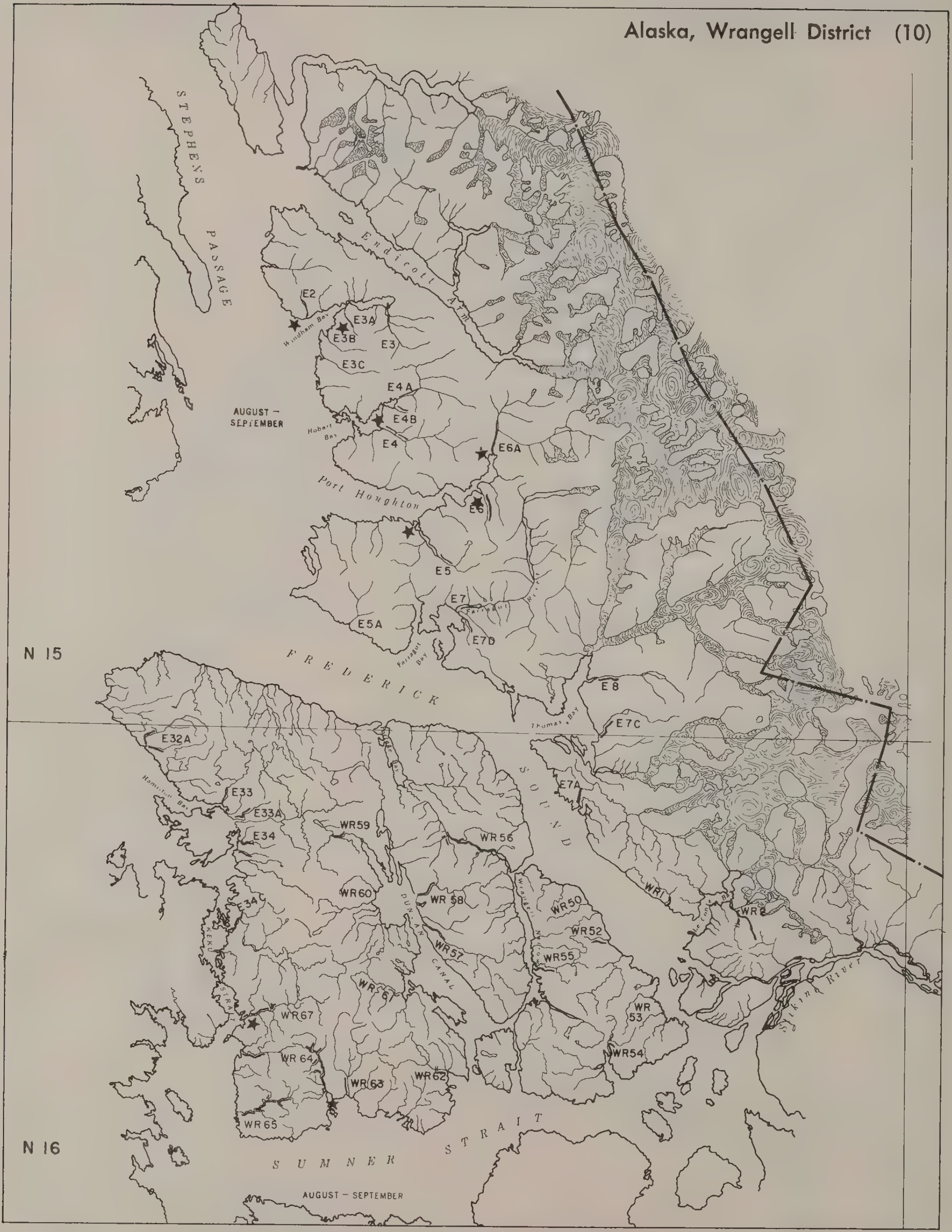
Alaska, Wrangell District (10)
STEPHENS PASSAGE
Endicott Arm
E2
Windham Bay
E3A
E3B
E3
E3C
E4A
AUGUST — SEPTEMBER
Hobart Bay
E4B
E4
E6A
Port Houghton
E6
E5
E7
Farragut River
E5A
E7D
Farragut Bay
N 15
FREDERICK SOUND
E8
Thomas Bay
E7C
E32A
Hamilton Bay
E33
E33A
E7A
WR59
WR56
E34
WR60
WR 58
DUNCAN CANAL
Wrangell Narrows
E34
KEKU STRAIT
WR50
WR52
WR57
WR55
WR1
WR2
WR 61
Stikine River
WR 53
WR67
WR 64
WR54
WR63
WR62
WR 65
N 16
SUMNER STRAIT
AUGUST — SEPTEMBER

FIGURE 37. Spawning grounds of pink salmon in Southeastern Alaska (Wrangell).

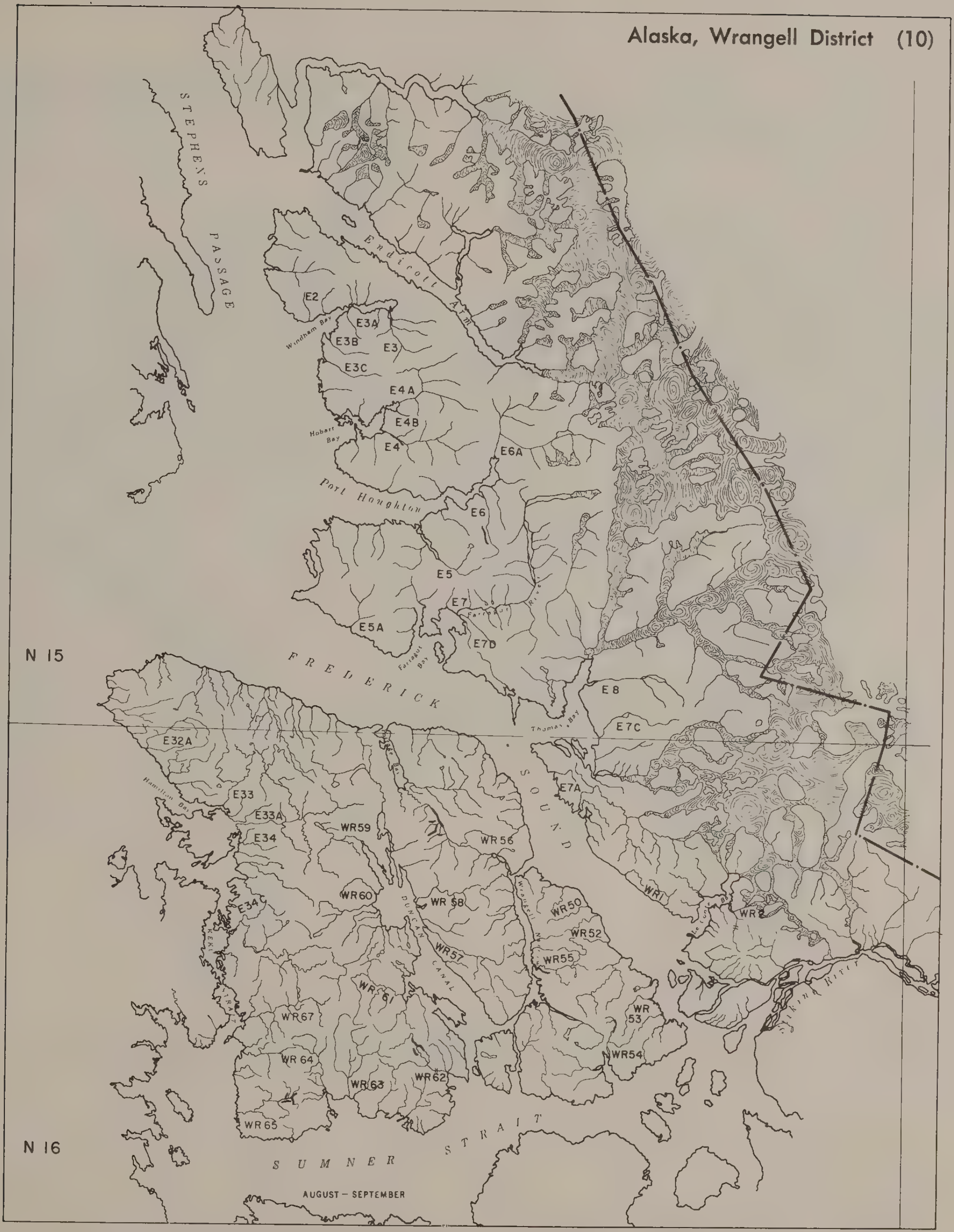
Alaska, Wrangell District (10)
STEPHENS PASSAGE
Endicott Arm
E2
Windham Bay
E3A
E3B
E3
E3C
E4A
Hobart Bay
E4B
E4
E6A
Port Houghton
E6
E5
E7
So. Farragut River
E5A
E7D
Farragut Bay
N 15
FREDERICK SOUND
E8
Thomas Bay
E7C
E32A
Hamilton Bay
E33
E33A
E34
WR59
WR56
E7A
WR1
Le Conte Bay
WR2
WR60
WR58
DUNCAN CANAL
E34C
KEKU STRAIT
WR50
Wrangell Narrows
WR52
WR57
WR55
WR61
WR67
WR 53
WR54
WR 64
WR63
WR62
WR65
Stikine River
N 16
SUMNER STRAIT
AUGUST – SEPTEMBER

FIGURE 38. Spawning grounds of sockeye salmon in Southeastern Alaska (Wrangell).

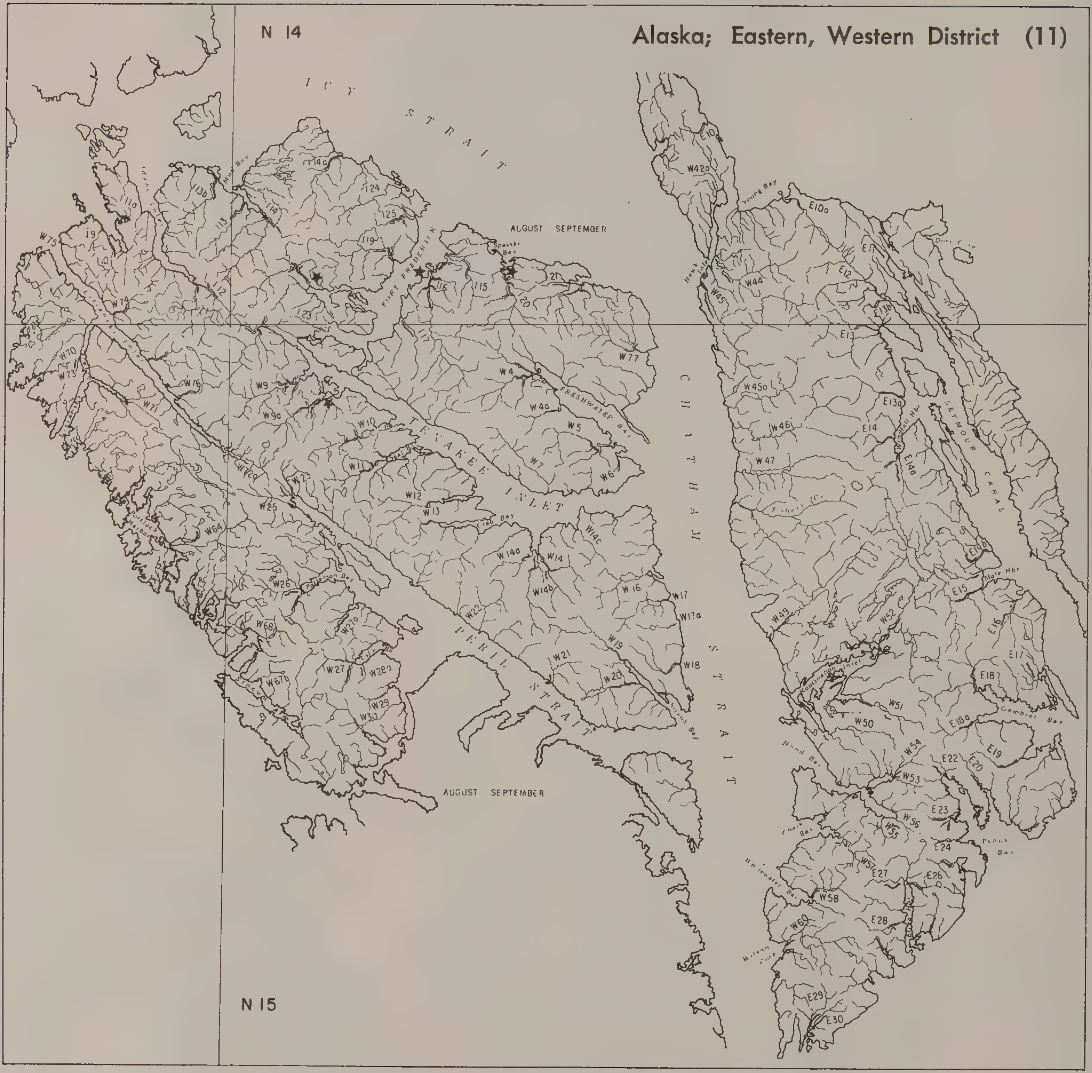
Alaska; Eastern, Western District (11)
N 14
N 15
ICY STRAIT
AUGUST SEPTEMBER
PORT FREDERICK
FRESHWATER BAY
TENAKEE INLET
PERIL STRAIT
CHATHAM STRAIT
SEYMOUR CANAL
AUGUST SEPTEMBER
Young Bay
Hawk Inlet
Mole Hbr
Gambier Bay
Hood Bay
Chaik Bay
Pybus Bay
Whitewater Bay
Wilson Cove
Kelp Bay
Pavlof Hbr
Spasski Bay
Game Bay
W75
W74
W70
W73
W76
W71
W9
W9a
W10
W11
W12a
W23
W25
W12
W13
W64
W26
W68
W27
W28a
W27a
W29
W30
W67b
W4
W4a
W5
W7
W6
W77
W14a
W14
W14c
W14b
W16
W17
W17a
W22
W19
W21
W20
W18
E10
W42a
E10a
E11
E12
W44
W45
E13b
E13
W45a
E13a
W46
E14
E14a
W47
E14b
E15
E16
E17
E18
W49
W52
W51
W50
E18a
E19
E20
E22
W54
W53
E23
W56
W55
E24
W57
E27
E26
W58
E28
W60
E29
E30
I20
I21
I15
I16
I17
I19
I23
I24
I25
I14
I14a
I13
I13b
I12
I11a
I9
I10

Figure 39. Spawning grounds of chum salmon in Southeastern Alaska (Eastern-Western).

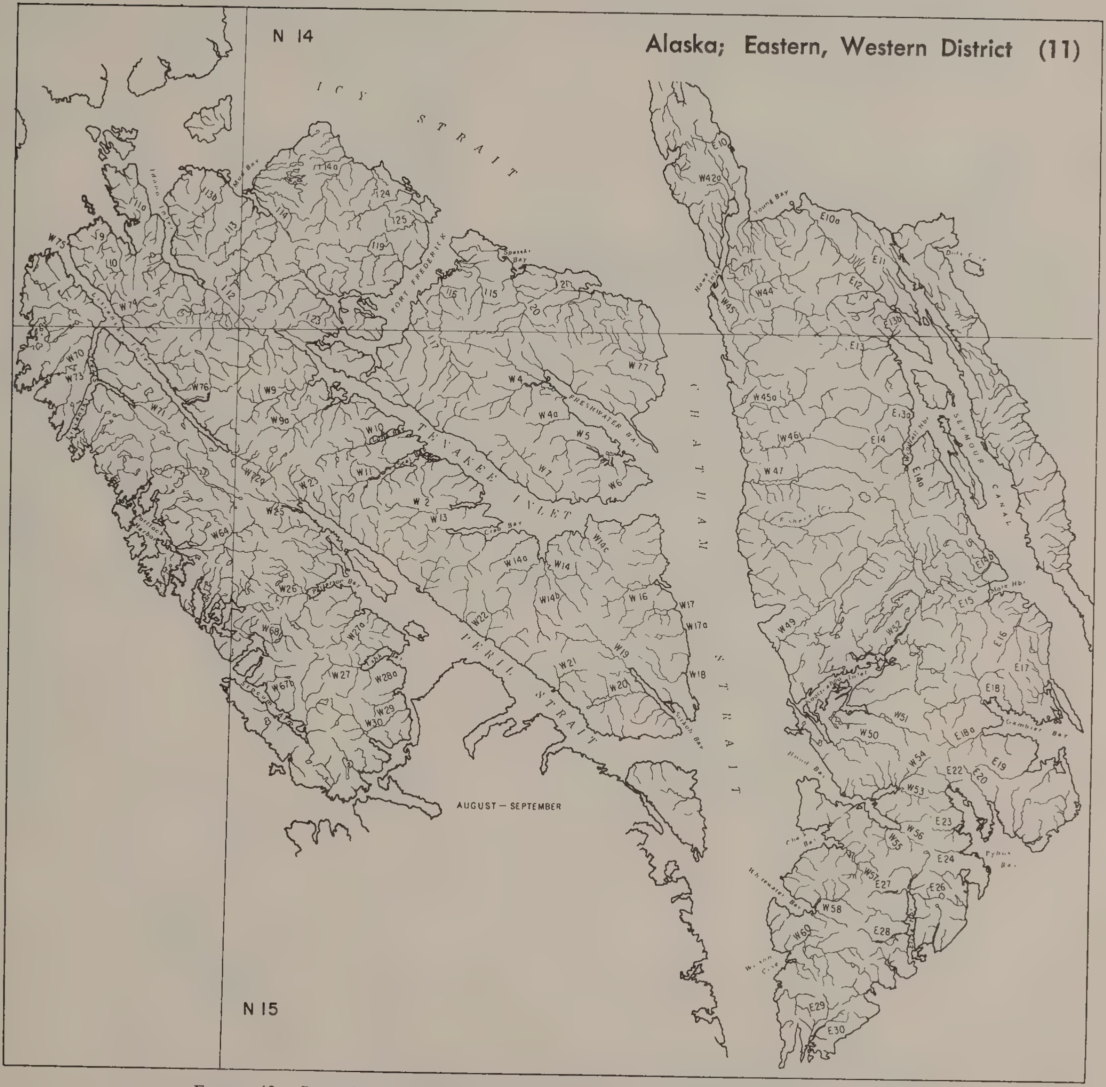
Alaska; Eastern, Western District (11)
N 14
N 15
ICY STRAIT
PORT FREDERICK
TENAKEE INLET
PERIL STRAIT
CHATHAM STRAIT
SEYMOUR CANAL
FRESHWATER BAY
AUGUST — SEPTEMBER
Idaho Inlet
Mud Bay
Spasski Bay
Lisianski Inlet
Lisianski
Portlock Harbor
Patterson Bay
Crab Bay
Seal Bay
Saook Bay
Slocum Arm
Sitkoh Bay
Young Bay
Hawk Inlet
Windfall Hbr
Mole Hbr
Gambier Bay
Kootznahoo Inlet
Hood Bay
Chaik Bay
Whitewater Bay
Wilson Cove
Pybus Bay
W75
V9
L10
110
113b
113
112
114a
114
124
125
119
116
115
120
121
123
117
W74
W70
W73
W76
W71
W72a
W9
W9a
W10
W11
W23
W25
W2
W13
W64
W26
W68
W27a
W27
W28a
W67b
W29
W30
W4
W4a
W5
W7
W6
W77
W14a
W14
W14c
W14b
W16
W17
W17a
W22
W19
W21
W20
W18
E10
W42a
E10a
E11
E12
W44
W45
E13b
E13
W45a
E13a
W46
E14
W47
E14a
E14b
E15
W49
W52
E16
E17
E18
W51
W50
E18a
E19
W54
E22
E20
W53
E23
W56
W55
E24
W57
E27
E26
W58
W60
E28
E29
E30

FIGURE 40. Spawning grounds of coho salmon in Southeastern Alaska (Eastern-Western).

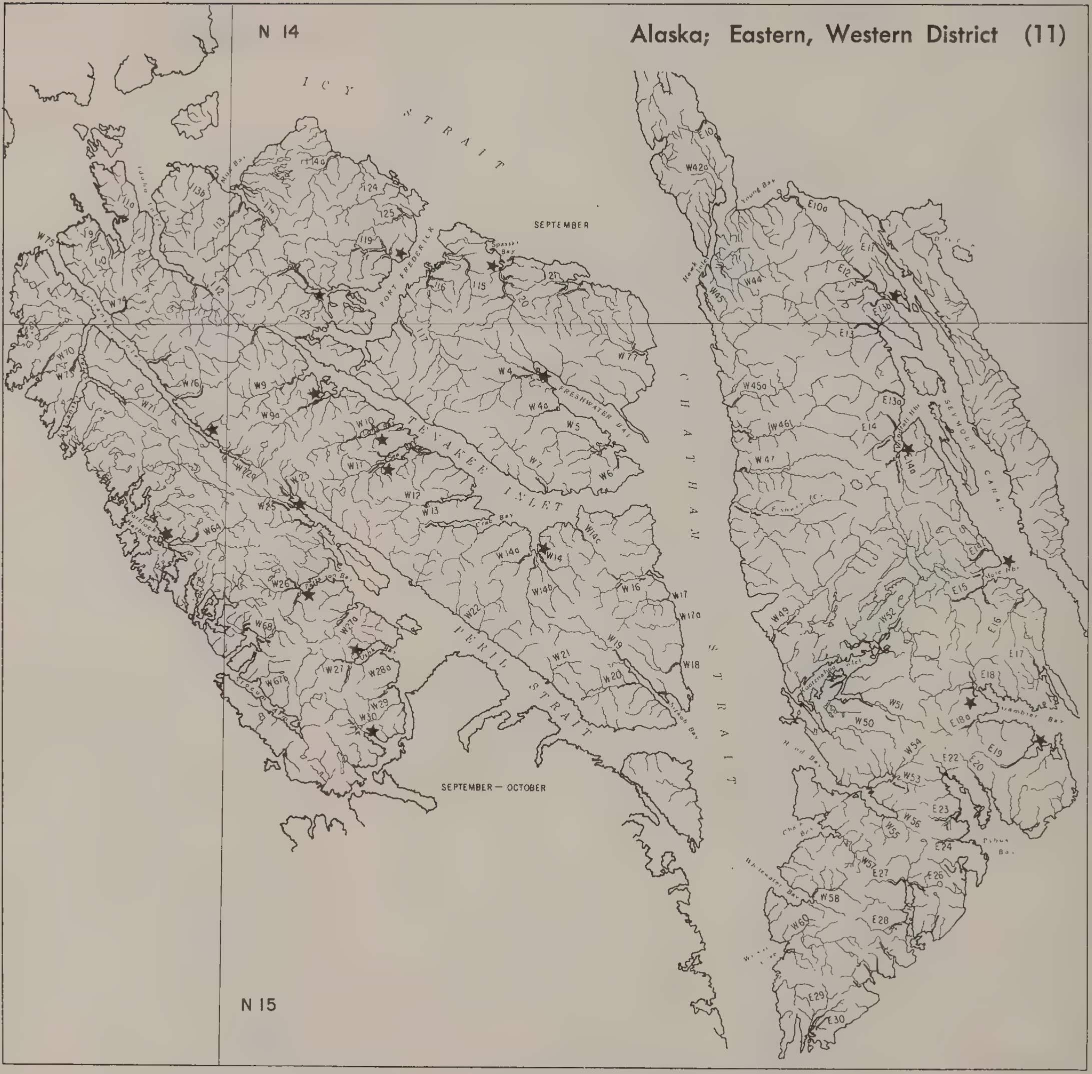
N 14
Alaska; Eastern, Western District (11)
ICY STRAIT
SEPTEMBER
PORT FREDERICK
FRESHWATER BAY
TENAKEE INLET
CHATHAM STRAIT
SEYMOUR CANAL
PERIL STRAIT
SEPTEMBER — OCTOBER
N 15
W75
W74
W70
W73
W76
W71
W72a
W9
W9a
W10
W11
W12
W13
W23
W25
W64
W26
W68
W27a
W27
W28a
W29
W30
W67b
W4
W4a
W5
W6
W7
W77
W14a
W14
W14b
W14c
W16
W17
W17a
W18
W19
W20
W21
W22
E10
W42a
E10a
E11
E12
W44
W45
E13b
E13
W45a
E13a
W46
E14
E14a
W47
E14
E15
E16
E17
E18
E18a
E19
E20
W49
W52
W51
W50
W54
W53
E22
E23
W56
W55
E24
W57
E27
E26
W58
W60
E28
E29
E30

Figure 41. Spawning grounds of pink salmon in Southeastern Alaska (Eastern-Western).

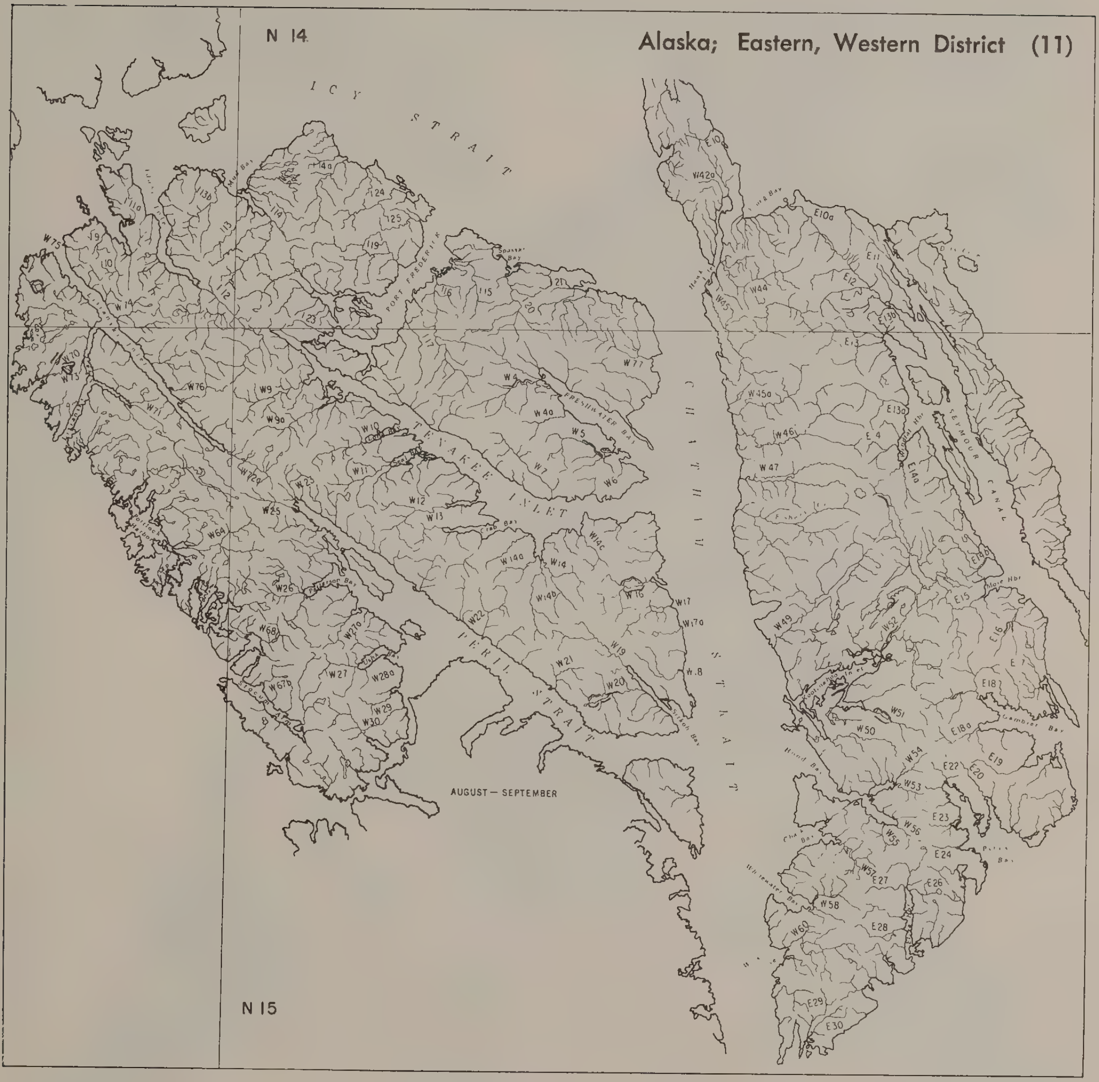
Alaska; Eastern, Western District (11)
N 14
N 15
ICY STRAIT
PORT FREDERICK
TENAKEE INLET
FRESHWATER BAY
PERIL STRAIT
CHATHAM STRAIT
SEYMOUR CANAL
AUGUST — SEPTEMBER
Mud Bay
Spasski Bay
Portlock Harbor
Patterson Bay
Crab Bay
Ushk Bay
Slocum Arm
Sitkoh Bay
Hawk In
Mitchell Bay
Kootznahoo Inlet
Hood Bay
Chaik Bay
Whitewater Bay
Mole Hbr
Gambier Bay
Pybus Bay
Windfall Hbr
114a
124
125
119
113b
111a
113
114
112
123
116
115
120
121
117
9
10
W75
W14
W70
W73
W76
W71
W9
W9a
W4
W4a
W5
W7
W6
W77
W10
W11
W12
W13
W72a
W23
W25
W64
W14a
W14b
W14c
W16
W17
W17a
W19
W21
W20
W.8
W22
W26
W68
W27a
W27
W28a
W29
W30
W67b
E10
W42a
E10a
E11
E12
W44
W45
E13b
E13
W45a
E13a
W46
E4
W47
E14a
E14b
E15
W49
W52
E16
E7
E18
W51
W50
E18a
E19
W54
E22
E20
W53
E23
W56
W55
E24
W57
E27
E26
W58
E28
W60
E29
E30

FIGURE 42. Spawning grounds of sockeye salmon in Southeastern Alaska (Eastern-Western).

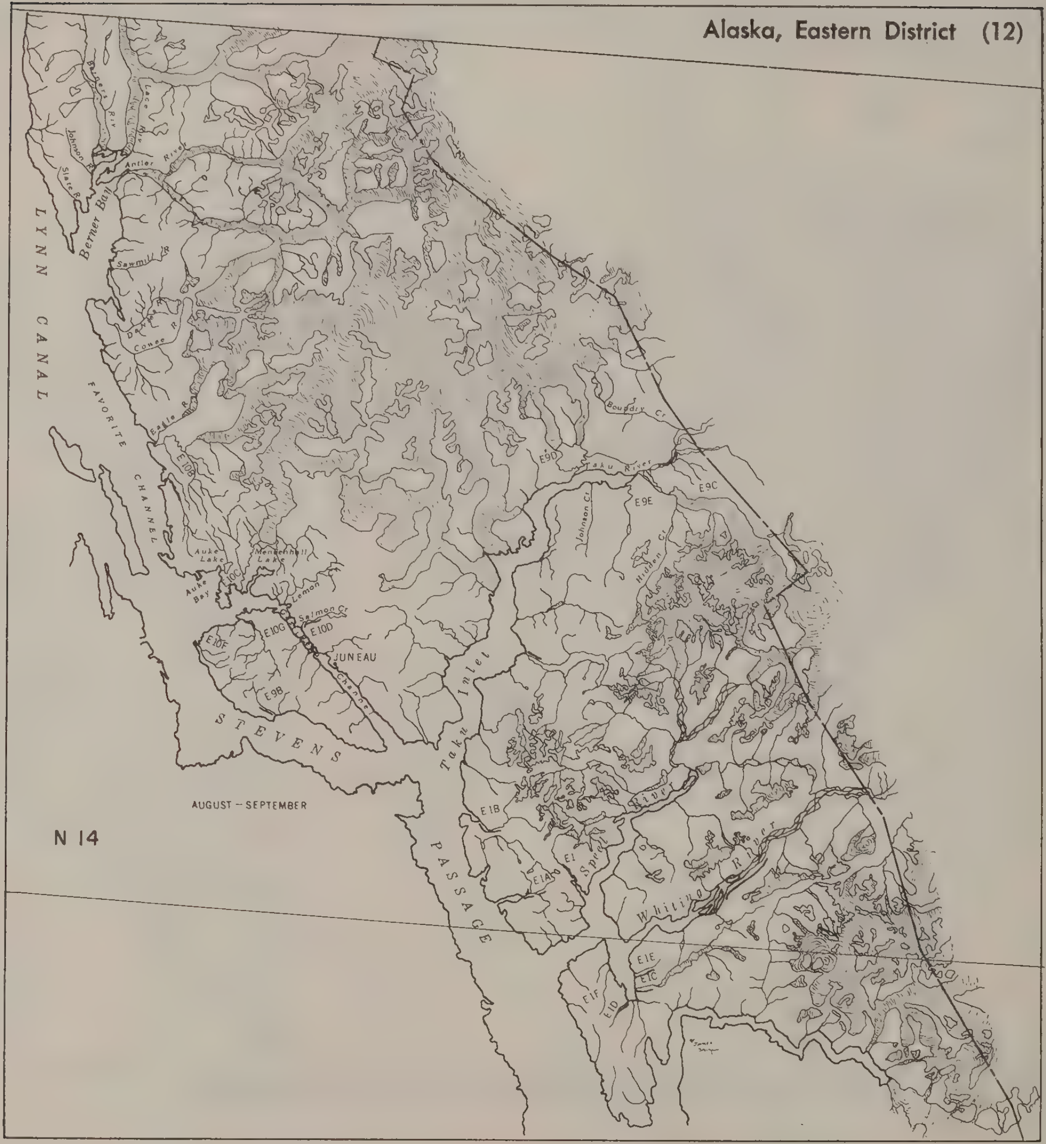
Alaska, Eastern District (12)
Berners Riv
Lace Riv
Johnson R
Slate R
Antler River
Berner Bay
LYNN CANAL
Sawmill R
Davies R
Cowee R
FAVORITE CHANNEL
Eagle R
E10B
Boundry Cr
E9D
Taku River
E9C
E9E
Johnson Cr
Hidden Cr
Auke Lake
Mendenhall Lake
Auke Bay
10C
Lemon
Salmon Cr
E10F
E10G
E10D
JUNEAU
E9B
Channel
Taku Inlet
STEVENS
PASSAGE
AUGUST – SEPTEMBER
N 14
E1B
River
E1
Speel
E1A
Whiting River
E1E
E1C
E1F
E1D

Figure 43. Spawning grounds of chum salmon in Southeastern Alaska (Eastern).

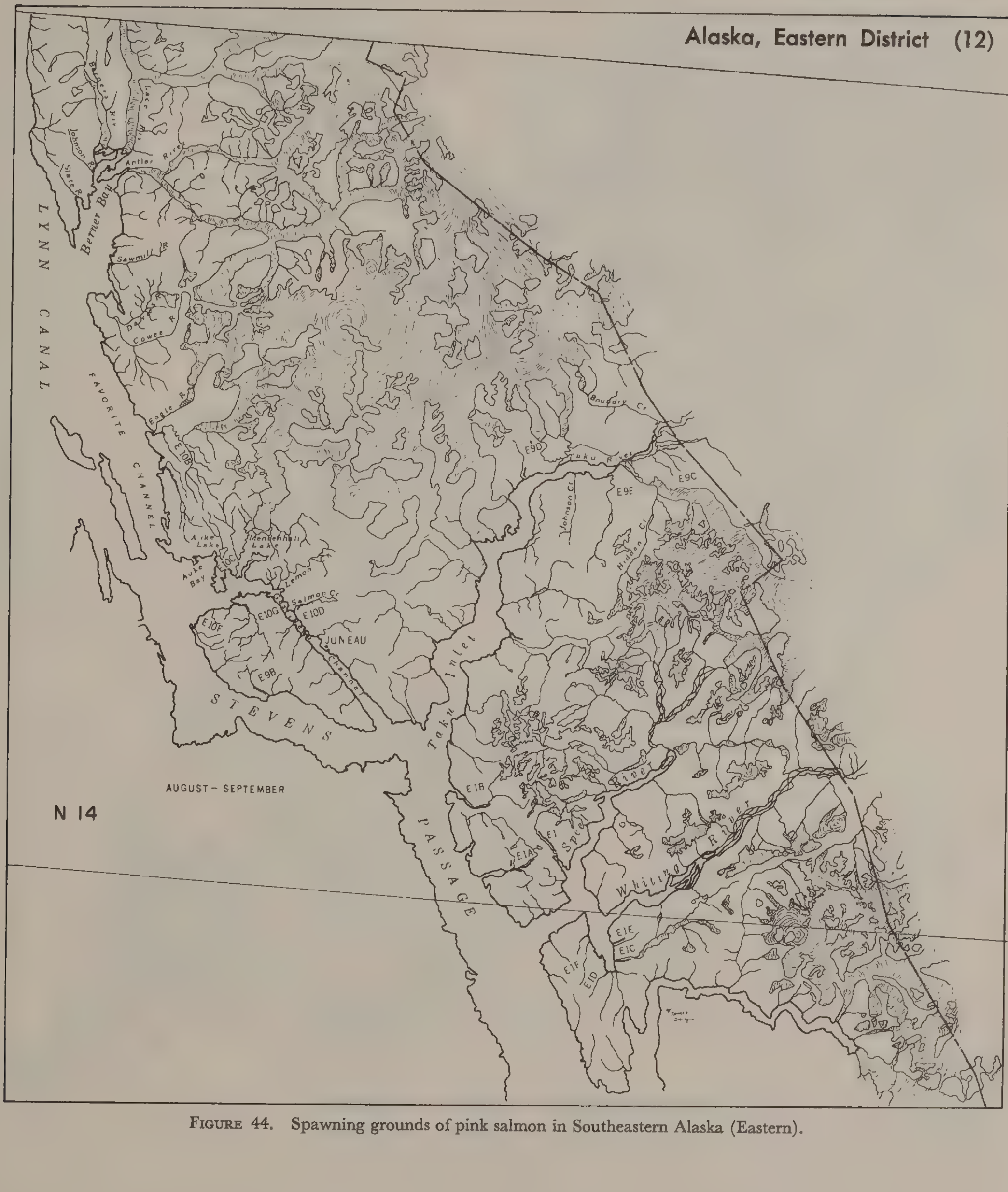
Alaska, Eastern District (12)
Berners Riv
Lace Riv
Johnson R
Slate R
Antler River
Berner Bay
LYNN CANAL
Sawmill R
Davies R
Cowee R
FAVORITE CHANNEL
Eagle R
E10B
Auke Lake
Mendenhall Lake
E10C
Auke Bay
Lemon
Salmon Cr
E10G
E10D
E10F
JUNEAU
Channel
E9B
STEVENS PASSAGE
Boundry Cr
E9D
Taku River
E9C
E9E
Johnson Cr
Hidden Cr
Taku Inlet
E1B
Speel River
E1
E1A
Whiting River
E1E
E1C
E1F
E1D
AUGUST – SEPTEMBER
N 14

Figure 44. Spawning grounds of pink salmon in Southeastern Alaska (Eastern).

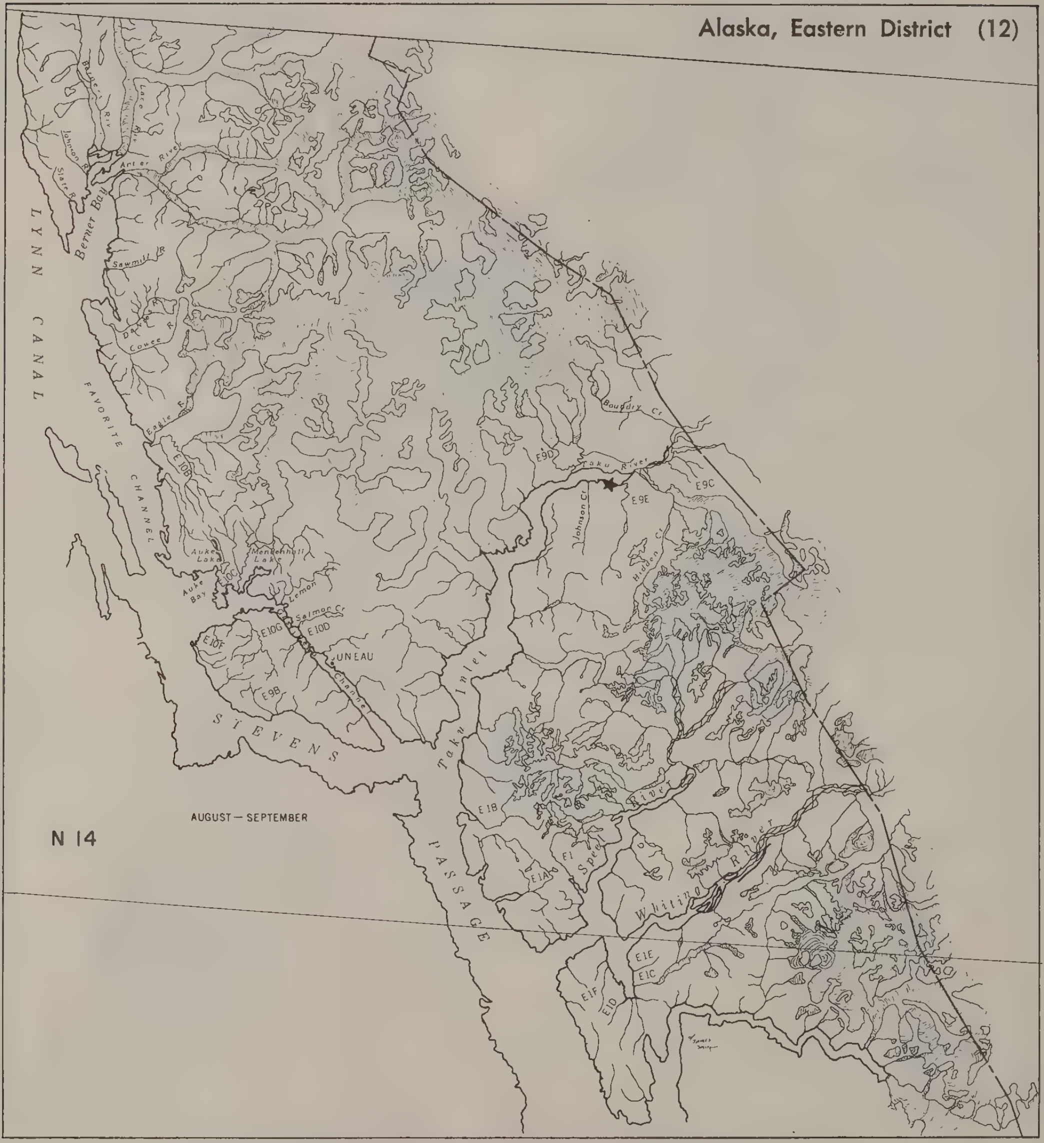
Alaska, Eastern District (12)
LYNN CANAL
FAVORITE CHANNEL
Berners Riv
Lace Riv
Johnson R
Slate R
Antler River
Berner Bay
Sawmill R
Davies R
Cowee R
Eagle R
E10B
Auke Lake
Mendenhall Lake
Auke Bay
E10C
Lemon Cr
Salmon Cr
E10G
E10D
E10F
JUNEAU
Channel
E9B
STEVENS PASSAGE
Taku Inlet
Taku River
Boundary Cr
E9D
E9C
E9E
Johnson Cr.
Hidden Cr.
Speel River
E1B
E1
E1A
Whiting River
E1E
E1C
E1F
E1D
AUGUST — SEPTEMBER
N 14

Figure 45. Spawning grounds of sockeye salmon in Southeastern Alaska (Eastern).

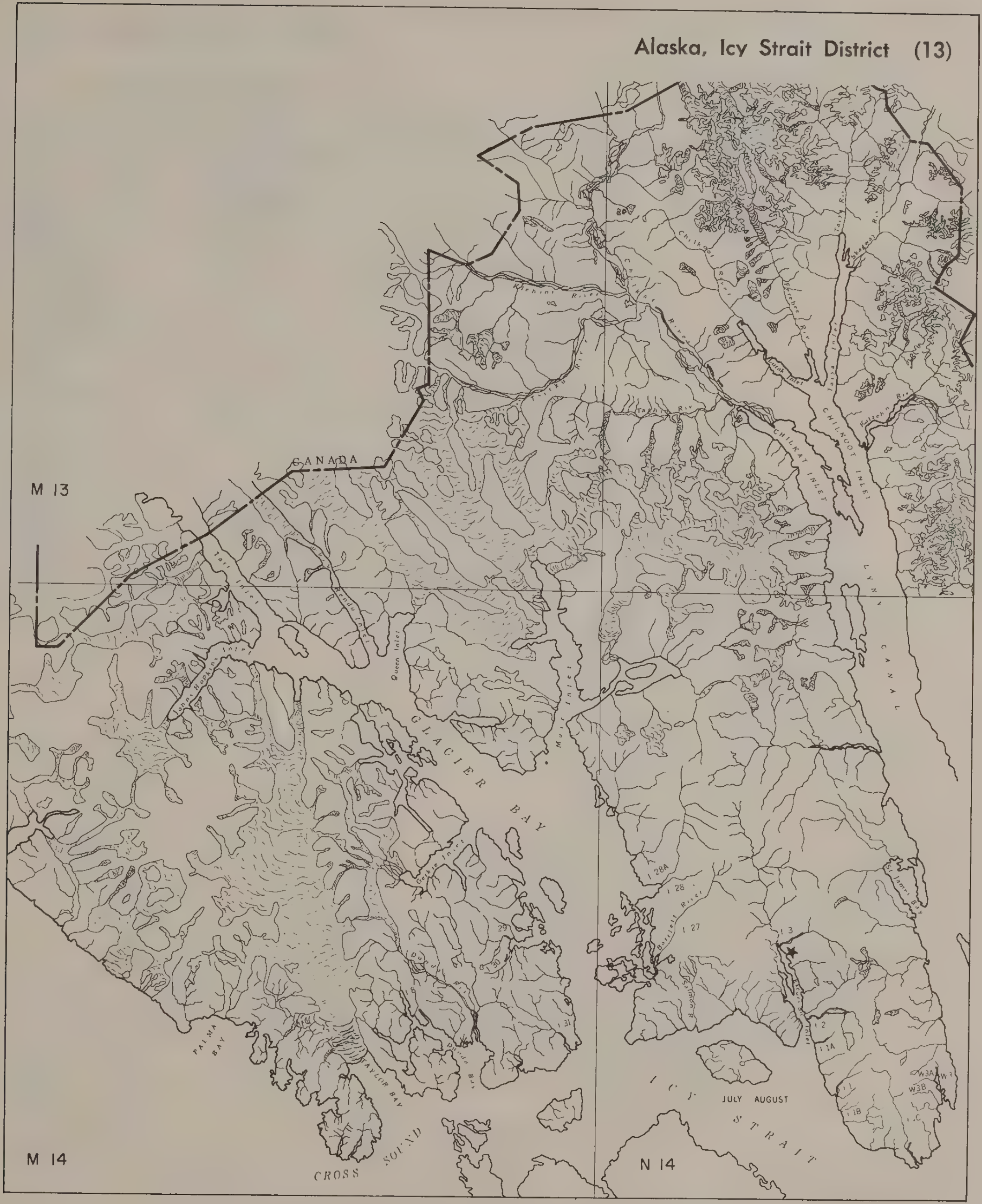
Alaska, Icy Strait District (13)
CANADA
M 13
M 14
N 14
Chilkat River
Chilkoot River
Klehini River
Tsirku River
Takhin River
CHILKAT INLET
CHILKOOT INLET
LYNN CANAL
GLACIER BAY
Queen Inlet
Muir Inlet
Johns Hopkins Inlet
Geikie Inlet
Dundas River
Dundas Bay
Bartlett River
Salmon R.
St. James Bay
I 28A
I 28
I 27
I 3
I 2
I 2A
I 1
I 1B
I C
W3A
W3B
29
I 30
I 31
JULY AUGUST
ICY STRAIT
TAYLOR BAY
PALMA BAY
CROSS SOUND

Figure 46. Spawning grounds of chum salmon in Southeastern Alaska (Icy Strait).

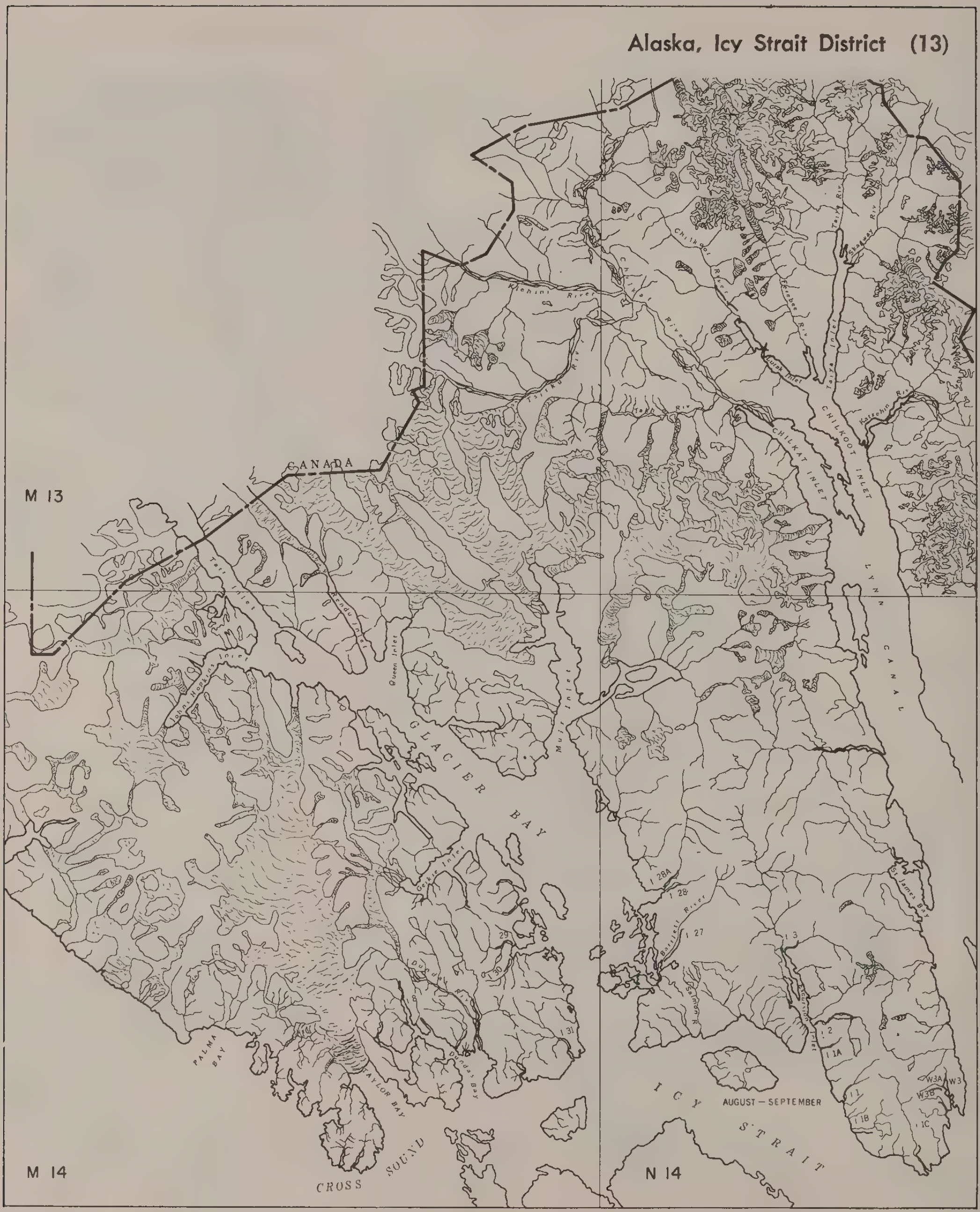
Alaska, Icy Strait District (13)
CANADA
M 13
M 14
N 14
Klehini River
Chilkat River
Chilkoot River
Ferebee Riv
Taiya Riv
Skagway Riv
Taiya Inlet
Lutak Inlet
Tsirku Riv
Takhin Riv
Katzehin Riv
CHILKAT INLET
CHILKOOT INLET
LYNN CANAL
Tarr Inlet
Reindeer Inlet
Johns Hopkins Inlet
Queen Inlet
Muir Inlet
GLACIER BAY
Geikie Inlet
Dundas Riv
Dundas Bay
TAYLOR BAY
PALMA BAY
CROSS SOUND
ICY STRAIT
AUGUST — SEPTEMBER
St. James Bay
Bartlett River
Salmon R
Excursion Inlet
28A
28
27
29
30
31
3
2
1A
1
1B
1C
W3A
W3
W3B

FIGURE 47. Spawning grounds of pink salmon in Southeastern Alaska (Icy Strait).

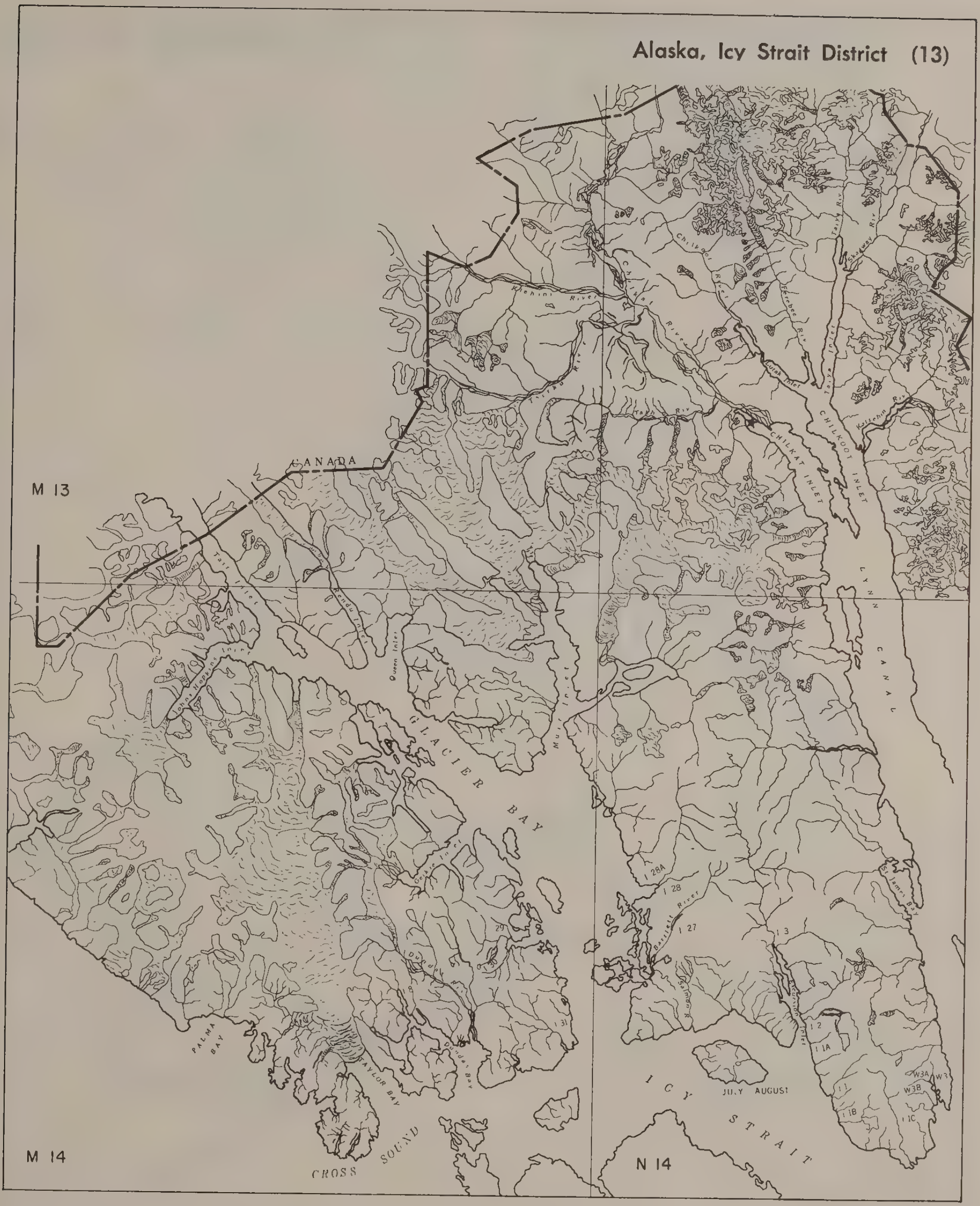
Alaska, Icy Strait District (13)
CANADA
M 13
M 14
N 14
Klehini River
Chilkat River
Chilkoot River
Ferebee Riv
Taiya Riv
Skagway Riv
Tsirku Riv
Takhin Riv
Katzehin Riv
Lutak Inlet
Taiya Inlet
CHILKAT INLET
CHILKOOT INLET
LYNN CANAL
Tarr Inlet
Queen Inlet
Muir Inlet
Geikie Inlet
GLACIER BAY
Dundas Riv
Dundas Bay
TAYLOR BAY
PALMA BAY
CROSS SOUND
ICY STRAIT
Bartlett River
Salmon R
Excursion Inlet
St James Bay
JULY
AUGUST
28A
28
27
29
30
31
3
2
1A
1
1B
1C
W3A
W3
W3B

FIGURE 48. Spawning grounds of sockeye salmon in Southeastern Alaska (Icy Strait).

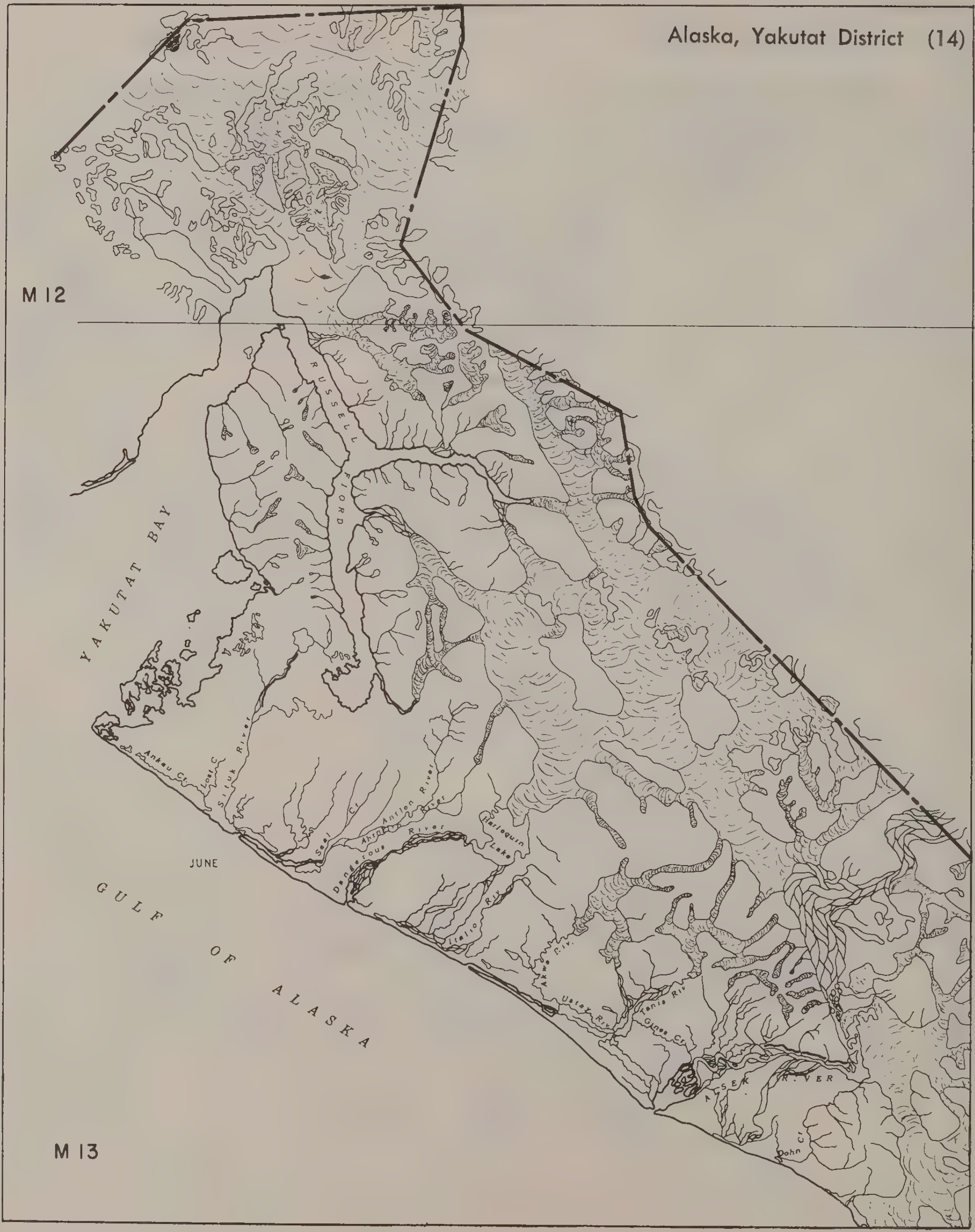
Alaska, Yakutat District (14)
M 12
M 13
RUSSELL FIORD
YAKUTAT BAY
GULF OF ALASKA
JUNE
Ankau Cr.
Lost C
Situk River
Seal Cr.
Antlen River
Ahrnklin River
Dangerous River
Harlequin Lake
Italio Riv.
Akwe Riv.
Ustay Riv.
Tanis Riv
Gines Cr.
ALSEK RIVER
John Cr.

Figure 49. Spawning grounds of chinook salmon in Southeastern Alaska (Yakutat).

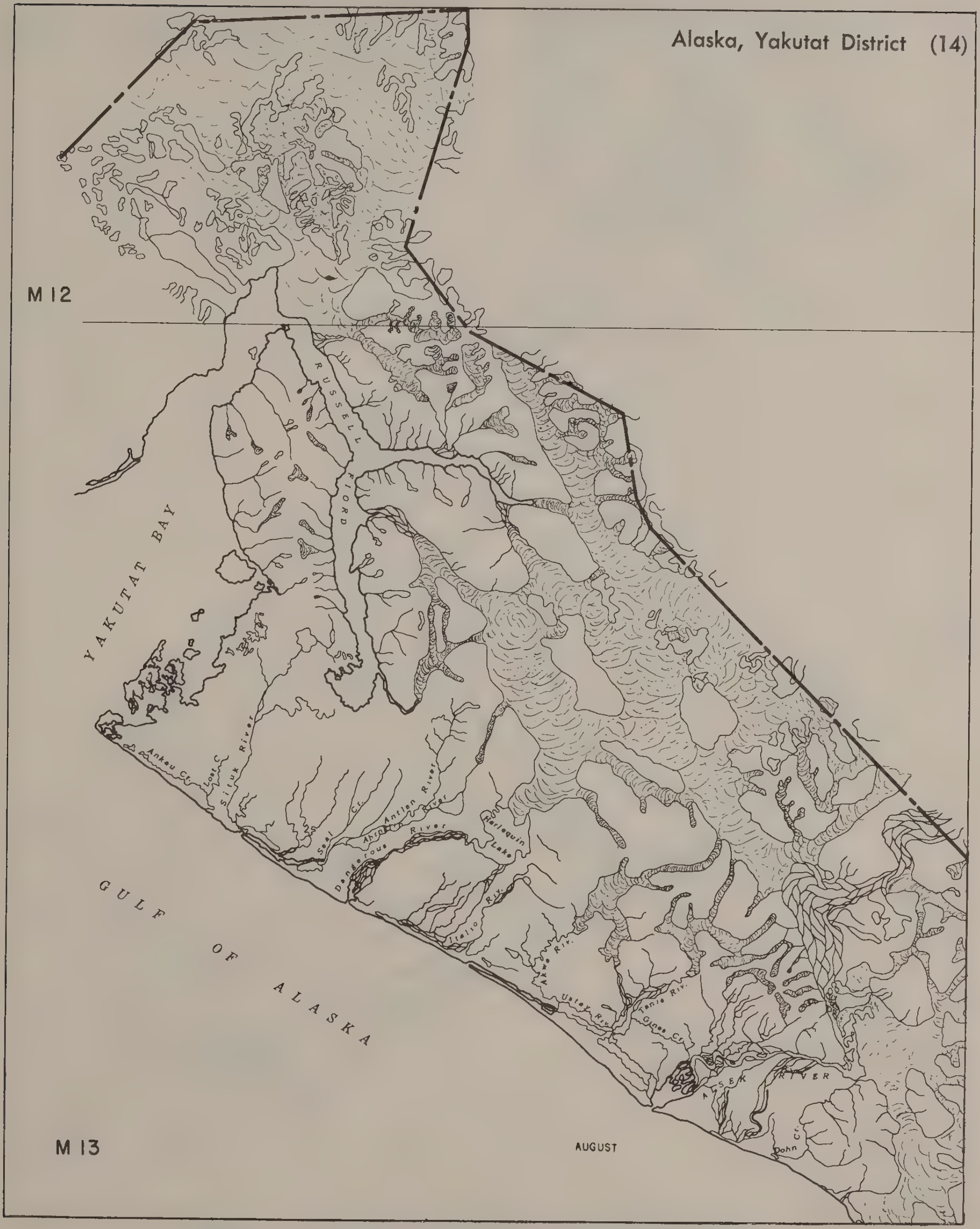
Alaska, Yakutat District (14)
M 12
RUSSELL FIORD
YAKUTAT BAY
Ankau Cr.
Lost C.
Situk River
Seal Cr.
Ahrnklin River
Antlen River
Dangerous River
Harlequin Lake
Italio Riv.
Akwe Riv.
Ustay Riv.
Tanis Riv.
Gines Cr.
ALSEK RIVER
Dohn Cr.
GULF OF ALASKA
M 13
AUGUST

FIGURE 50. Spawning grounds of chum salmon in Southeastern Alaska (Yakutat).

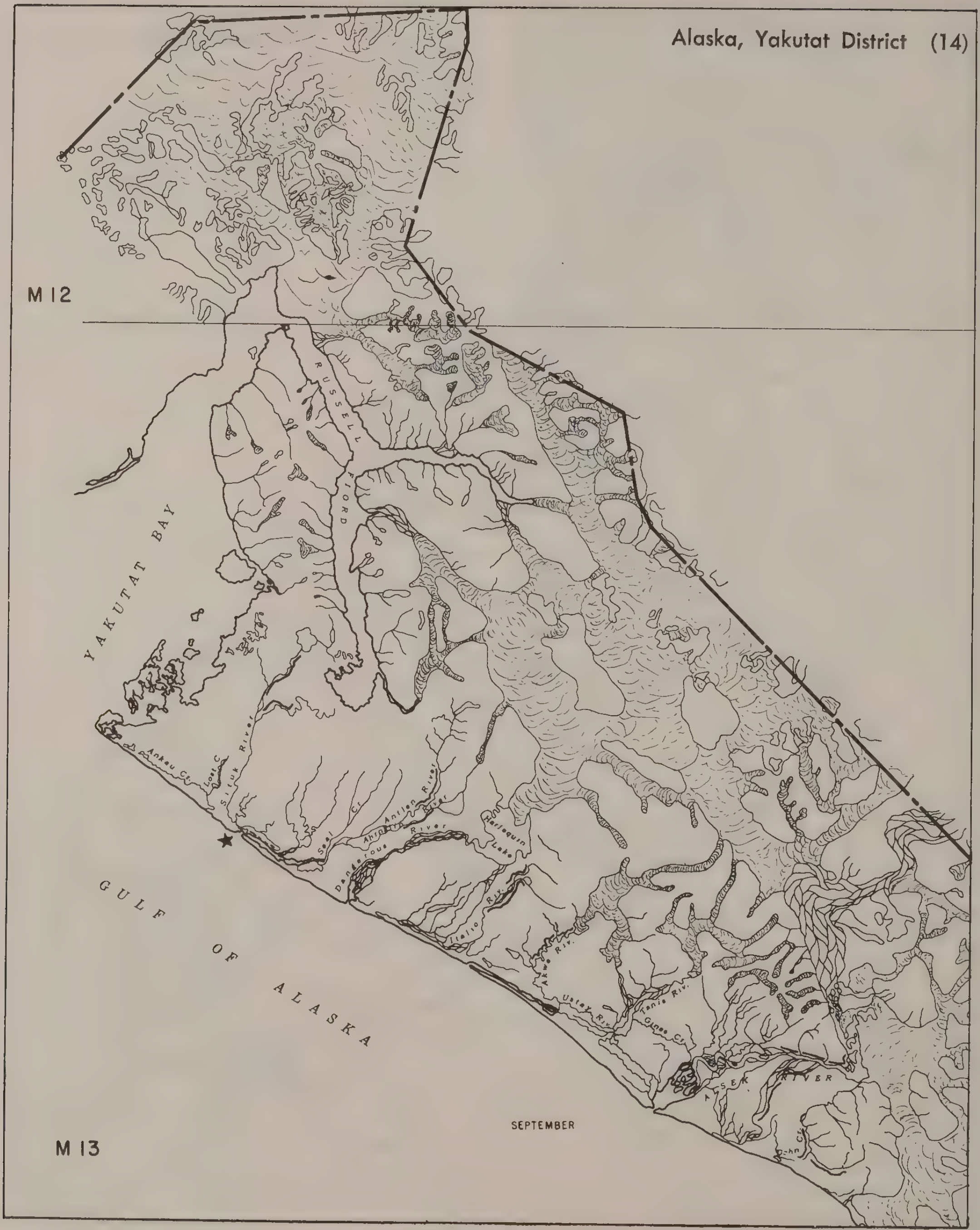
Alaska, Yakutat District (14)
M 12
M 13
RUSSELL FIORD
YAKUTAT BAY
GULF OF ALASKA
Ankau Cr.
Lost C.
Situk River
Seal Cr.
Ahrnklin River
Antlen River
Dangerous River
Harlequin Lake
Italio Riv.
Akwe Riv.
Ustay Riv.
Tanis Riv.
Gines Cr.
ALSEK RIVER
John Cr.
SEPTEMBER

FIGURE 51. Spawning grounds of coho salmon in Southeastern Alaska (Yakutat).

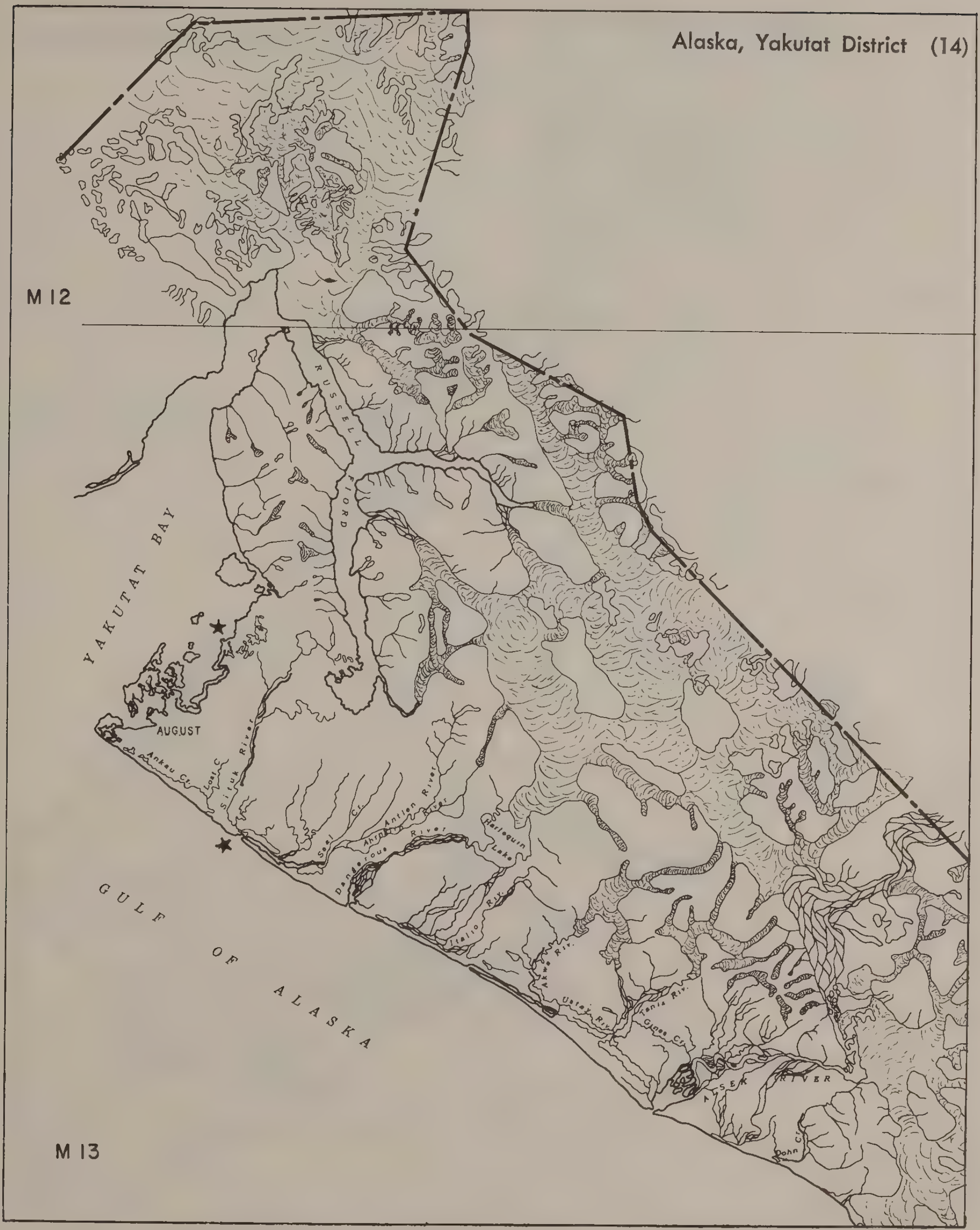
Alaska, Yakutat District (14)
M 12
M 13
RUSSELL FIORD
YAKUTAT BAY
AUGUST
Ankau Cr.
Lost C.
Situk River
Seal Cr.
Ahrnklin River
Antlen River
Dangerous River
Harlequin Lake
Italio Riv.
Akwe Riv.
Ustay Riv.
Tanis Riv.
Gines Cr.
ALSEK RIVER
John Cr.
GULF OF ALASKA

FIGURE 52. Spawning grounds of pink salmon in Southeastern Alaska (Yakutat).

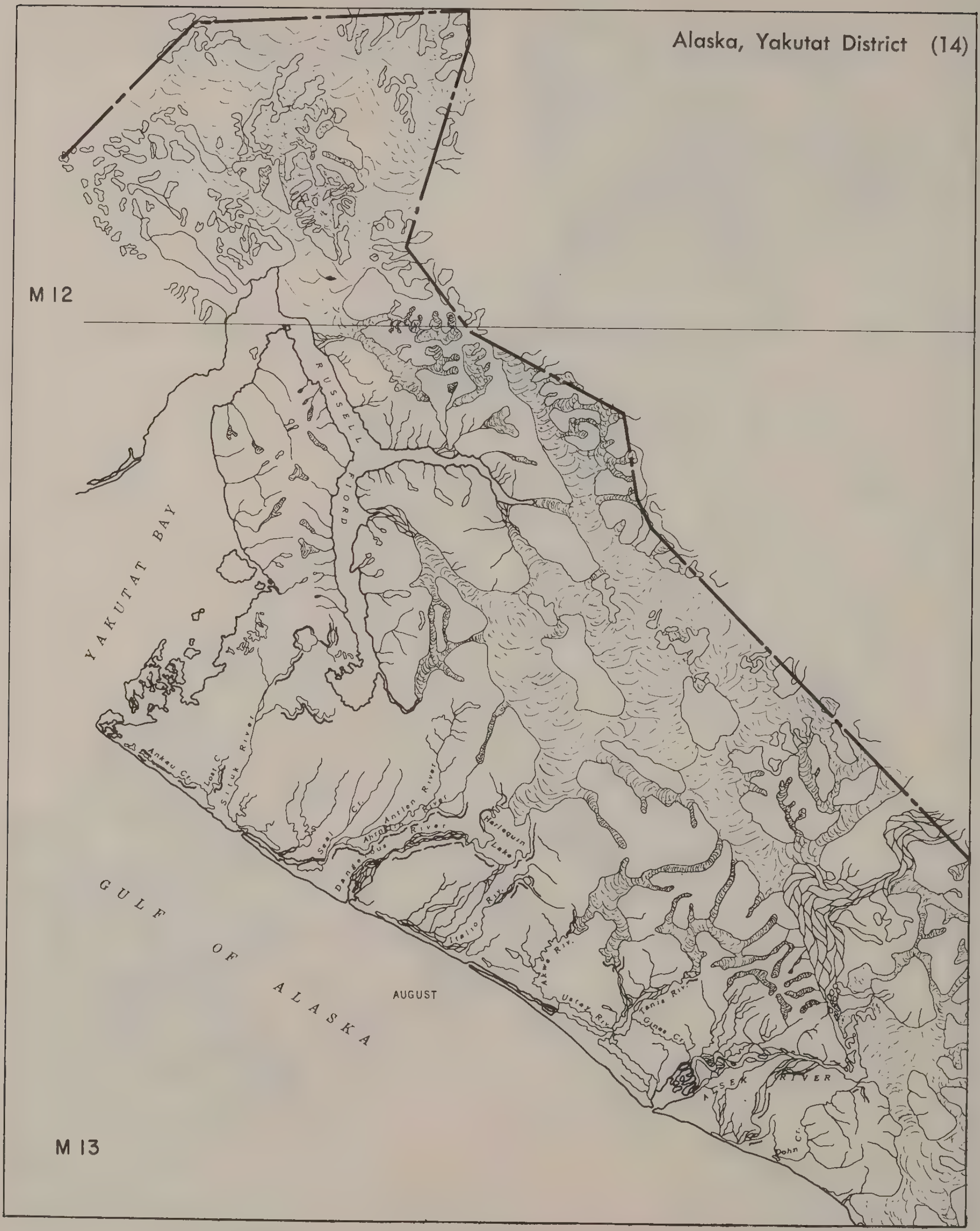
Alaska, Yakutat District (14)
M 12
M 13
RUSSELL FIORD
YAKUTAT BAY
GULF OF ALASKA
AUGUST
Ankau Cr.
Lost C.
Situk River
Seal Cr.
Ahrnklin River
Antlen River
Dangerous River
Harlequin Lake
Italio Riv.
Akwe Riv.
Ustay Riv.
Tanis Riv.
Gines Cr.
ALSEK RIVER
Dohn Cr.

Figure 53. Spawning grounds of sockeye salmon in Southeastern Alaska (Yakutat).

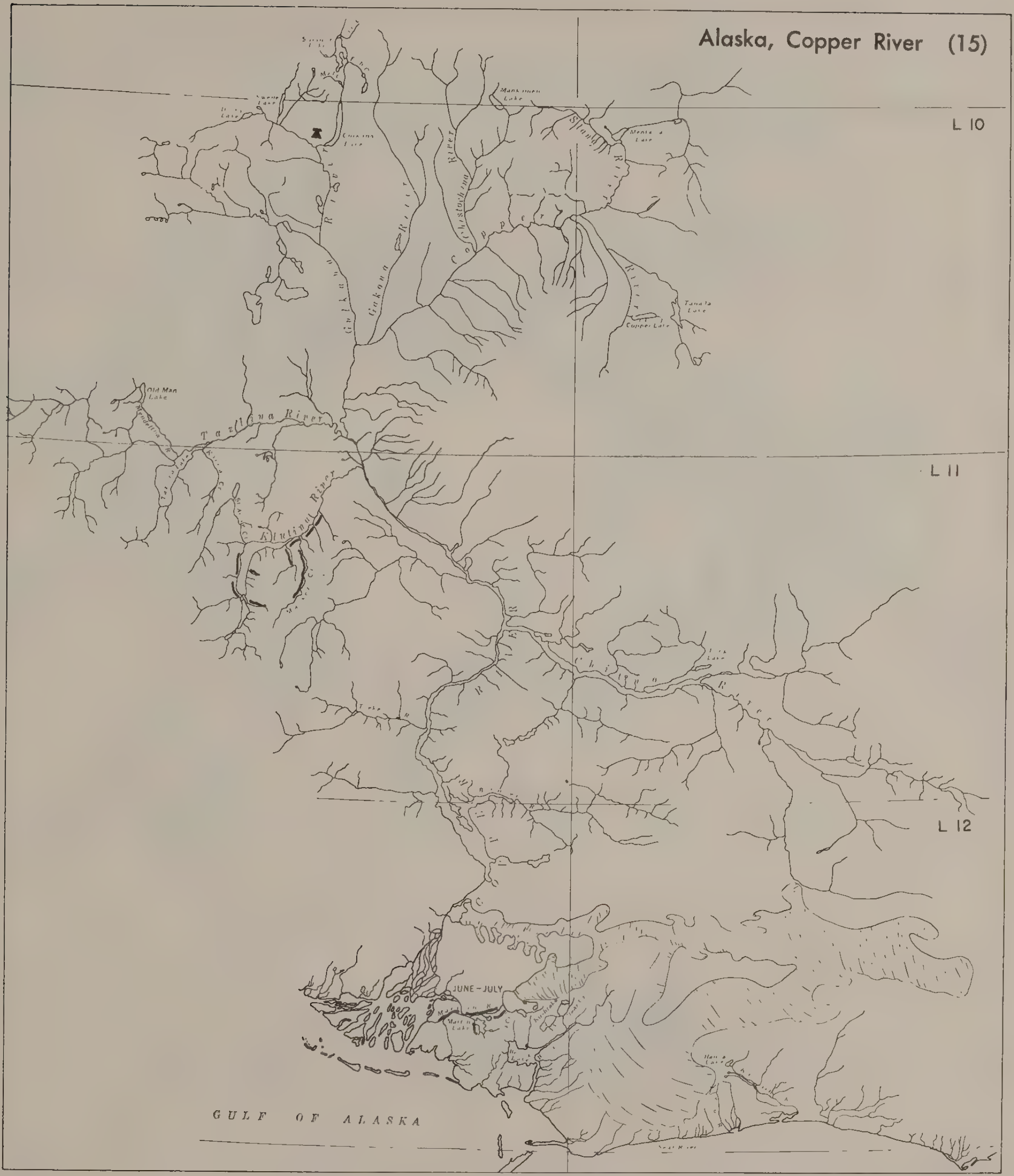
Alaska, Copper River (15)
L 10
L 11
L 12
Mankomen Lake
Copper River
Gulkana River
Gakona River
Chistochina River
Slana River
Copper Lake
Tanada Lake
Old Man Lake
Mendeltna R
Tazlina River
Klutina River
Tebay R
Chitina River
JUNE-JULY
GULF OF ALASKA

Figure 54. Spawning grounds of coho salmon in Central Alaska (Copper River).

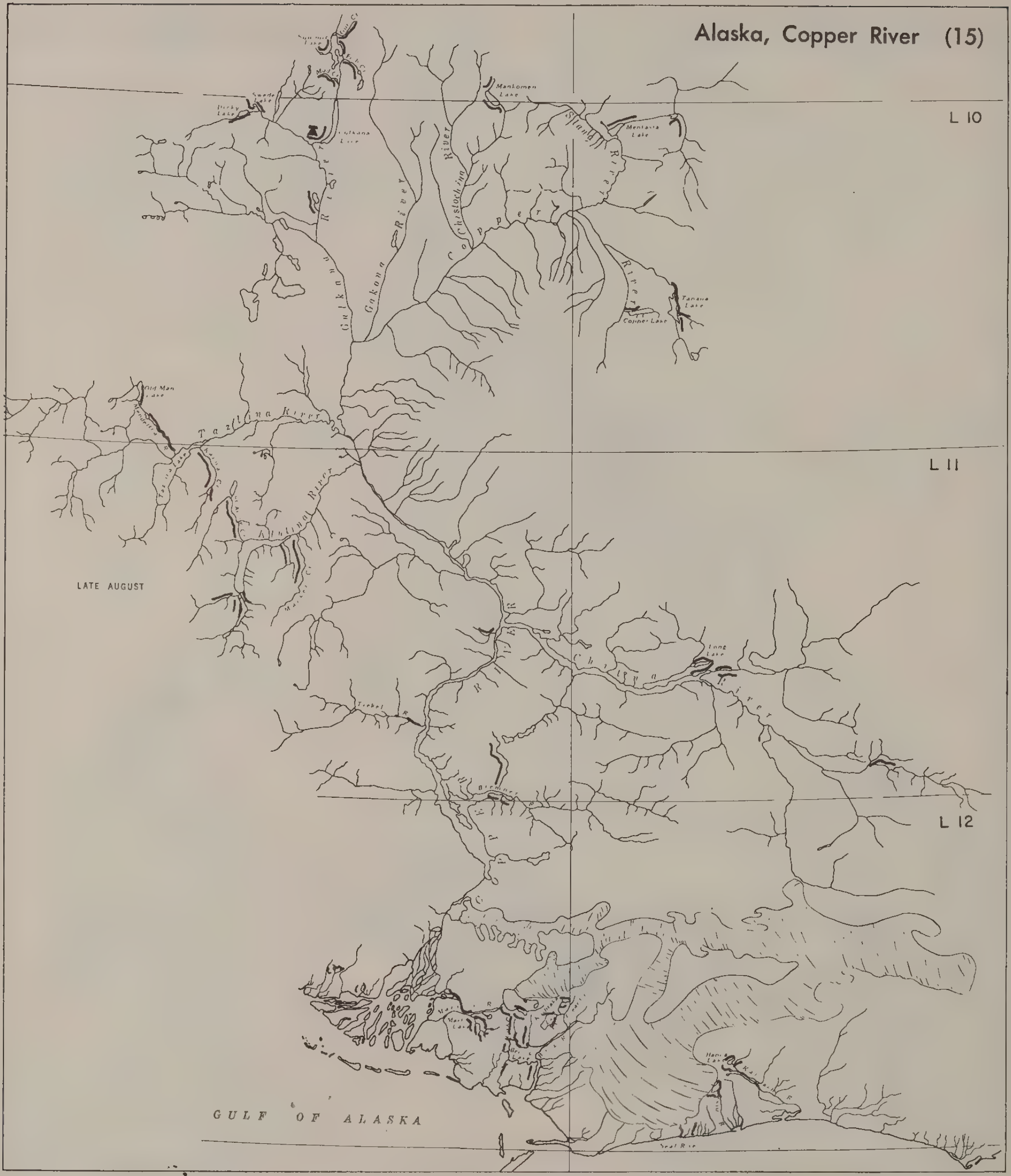
Alaska, Copper River (15)
L 10
L 11
L 12
Summit Lake
Gun Cr.
Fish Cr.
Mud Cr.
Swede Lake
Dicky Lake
Gulkana Lake
Gulkana River
Gakona River
Chistochina River
Mankomen Lake
Slana
River
Mentasta Lake
Copper River
River
Tanada Lake
Copper Lake
Old Man Lake
Mendeltna R.
Tazlina River
Tazlina Lake
Kaina Cr.
Klutina River
Manker Cr.
LATE AUGUST
Tiekel R.
RIVER
Chitina River
Long Lake
Bremner R.
Martin R.
Martin Lake
Bering Lake
Kaliakh R.
Seal Riv.
GULF OF ALASKA

FIGURE 55. Spawning grounds of sockeye salmon in Central Alaska (Copper River).

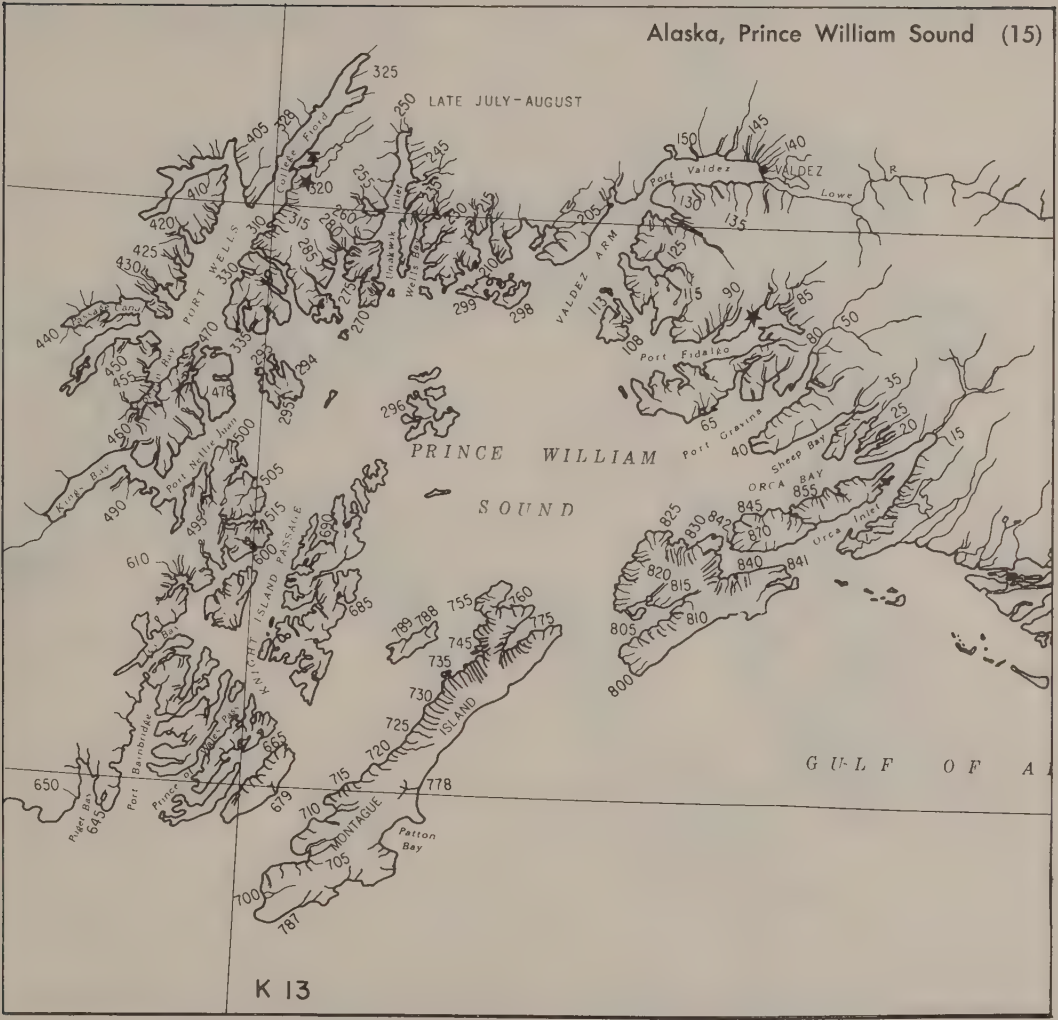
Alaska, Prince William Sound (15)
LATE JULY-AUGUST
325
250
328
405
College Fiord
320
410
255
245
235
260
315
310
280
285
420
425
430
PORT WELLS
330
Unakwik Inlet
Wells Bay
230
215
210
275
270
299
298
205
Port Valdez
150
145
140
VALDEZ
130
135
Lowe
R
VALDEZ ARM
125
113
115
90
85
108
Port Fidalgo
80
50
Passage Canal
440
470
335
293
294
450
455
Bay
478
295
296
460
500
Port Nellie Juan
King Bay
490
505
495
515
PRINCE WILLIAM SOUND
65
Port Gravina
40
35
25
20
15
Sheep Bay
ORCA BAY
855
845
825
830
842
870
Orca Inlet
840
841
820
815
810
805
800
610
600
KNIGHT ISLAND PASSAGE
690
685
Bay
789
788
755
760
775
745
735
730
725
Port Bainbridge
Prince of Wales Pass
665
720
715
778
650
Puget Bay
645
679
710
MONTAGUE ISLAND
Patton Bay
705
700
787
GULF OF A
K 13

FIGURE 56. Spawning grounds of chum salmon in Central Alaska (Prince William Sound).

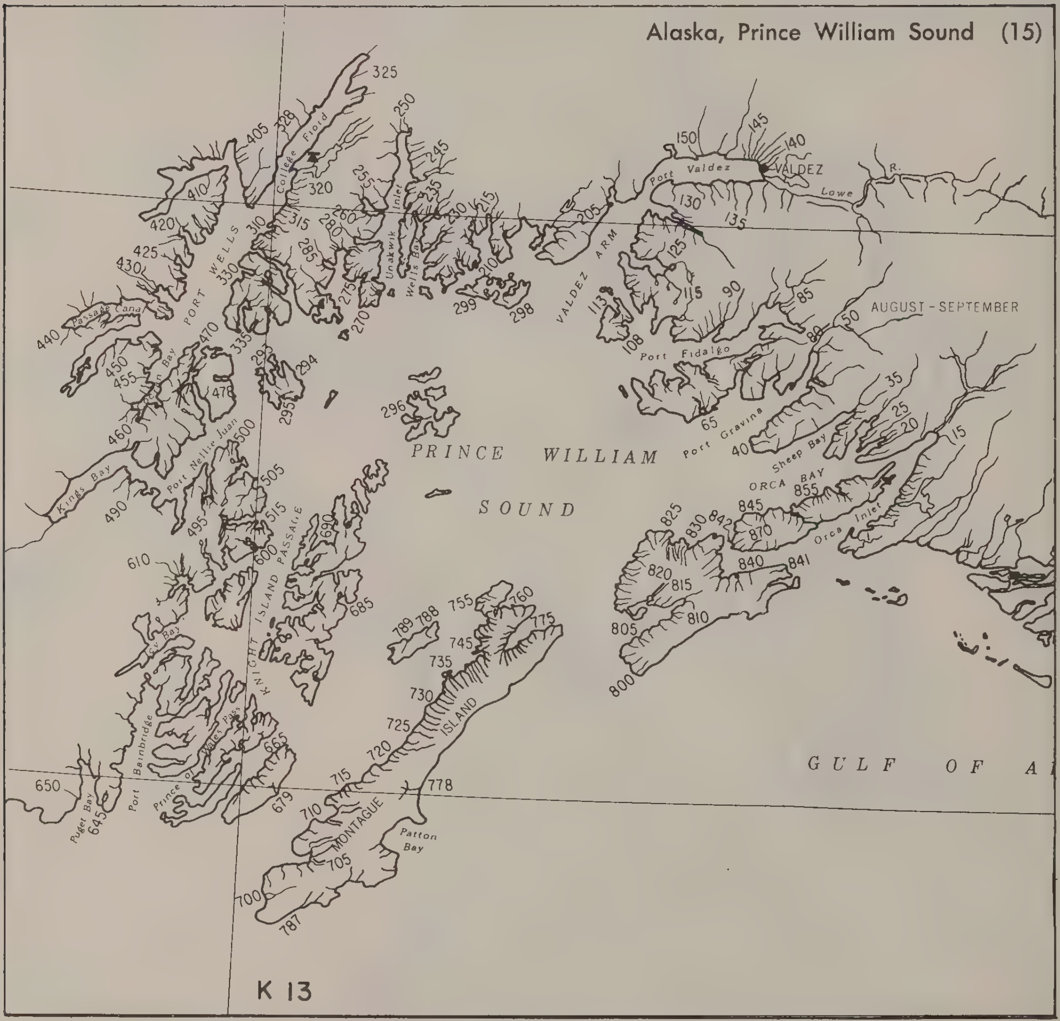
Alaska, Prince William Sound (15)
AUGUST - SEPTEMBER
K 13
PRINCE WILLIAM SOUND
GULF OF A
Port Valdez
VALDEZ
Lowe R.
VALDEZ ARM
Port Fidalgo
Port Gravina
Sheep Bay
ORCA BAY
Orca Inlet
PORT WELLS
College Fiord
Unakwik Inlet
Wells Bay
Passage Canal
Port Nellie Juan
Kings Bay
Icy Bay
Port Bainbridge
Puget Bay
Prince of Wales Pass
KNIGHT ISLAND PASSAGE
MONTAGUE ISLAND
Patton Bay
325
328
405
410
420
425
430
440
450
455
460
470
478
490
495
500
505
515
600
610
650
645
665
679
685
690
700
705
710
715
720
725
730
735
745
755
760
775
778
787
788
789
800
805
810
815
820
825
830
840
841
842
845
855
870
310
315
320
330
335
280
285
260
255
250
245
235
230
215
210
205
270
275
293
294
295
296
298
299
150
145
140
130
135
125
113
108
115
90
85
80
50
65
40
35
25
20
15

Figure 57. Spawning grounds of coho salmon in Central Alaska (Prince William Sound).

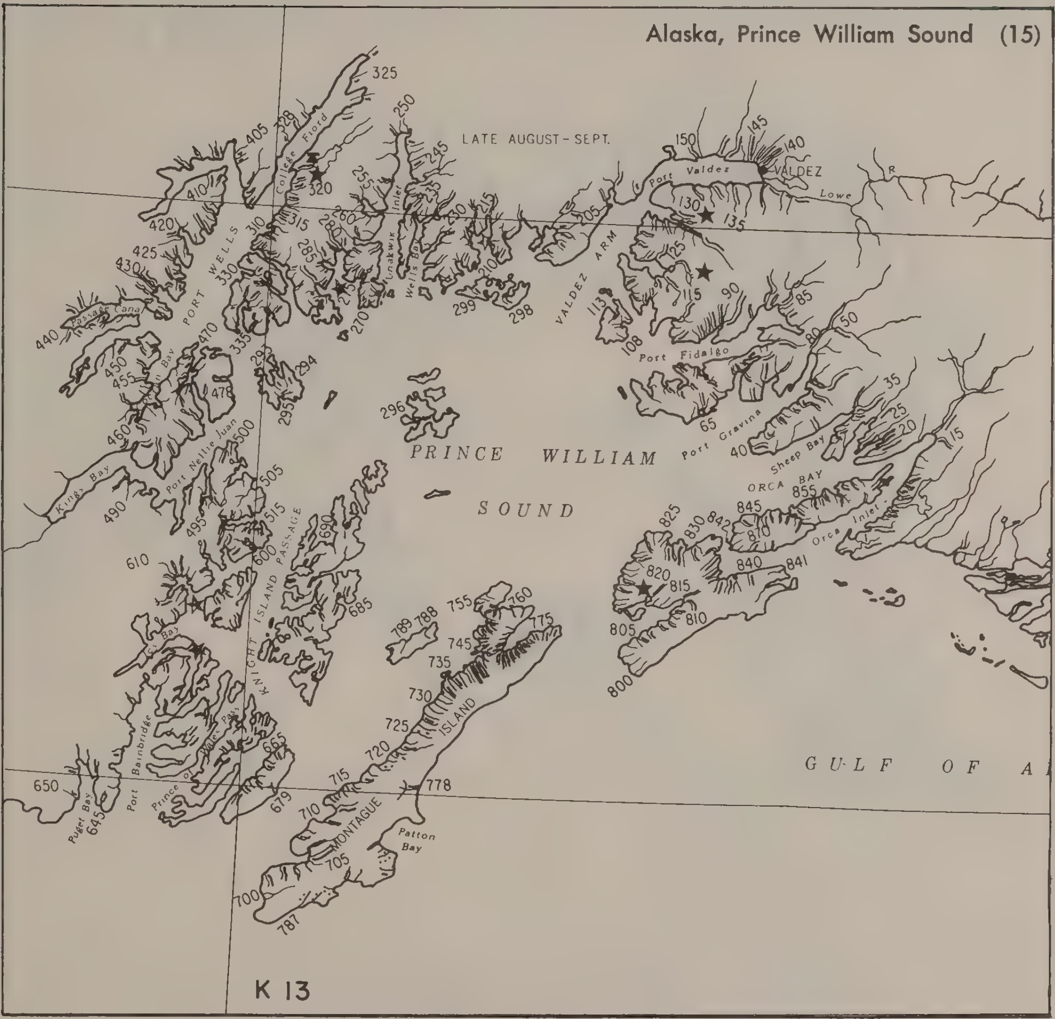
Alaska, Prince William Sound (15)
LATE AUGUST - SEPT.
PRINCE WILLIAM SOUND
GULF OF A
Port Valdez
VALDEZ
Lowe
R
VALDEZ ARM
Port Fidalgo
Port Gravina
Sheep Bay
ORCA BAY
Orca Inlet
College Fiord
Unakwik Inlet
Wells Bay
PORT WELLS
Passage Canal
Port Nellie Juan
Kings Bay
KNIGHT ISLAND PASSAGE
MONTAGUE ISLAND
Patton Bay
Port Bainbridge
Prince of Wales Pass.
Puget Bay
K 13
325
250
245
150
145
140
320
328
405
410
420
425
430
440
310
315
330
335
255
260
280
285
230
215
210
205
130
135
125
115
90
85
113
108
80
50
35
25
20
15
65
40
299
298
294
293
295
296
270
470
450
455
478
460
500
505
515
490
495
600
610
690
685
650
645
665
679
755
760
775
745
735
788
789
730
725
720
715
710
705
700
787
778
825
830
842
845
855
870
840
841
820
815
810
805
800

FIGURE 58. Spawning grounds of pink salmon in Central Alaska (Prince William Sound).

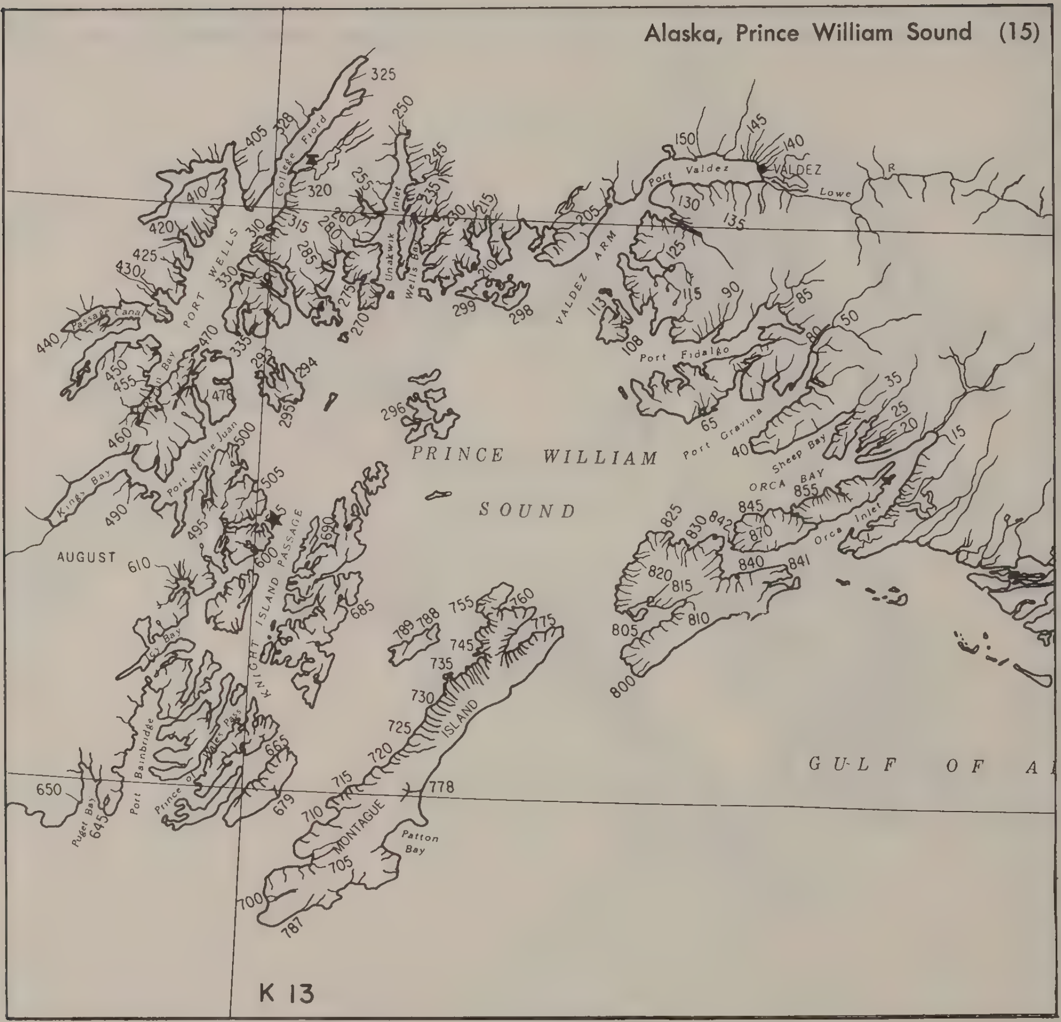
Alaska, Prince William Sound (15)
325
250
245
405
328
College Fiord
320
255
Unakwik Inlet
235
Wells Bay
150
145
140
Port Valdez
VALDEZ
Lowe
R
410
420
425
430
PORT WELLS
310
315
280
260
230
215
205
130
135
VALDEZ ARM
125
Passage Canal
440
330
285
275
270
210
299
298
113
115
90
85
80
50
470
335
293
294
108
Port Fidalgo
450
455
478
295
296
65
35
25
20
15
460
Port Nellie Juan
500
PRINCE WILLIAM
Port Gravina
40
Sheep Bay
Kings Bay
490
495
505
SOUND
ORCA BAY
855
845
825
830
842
870
Orca Inlet
AUGUST
610
600
690
KNIGHT ISLAND PASSAGE
840
841
820
815
810
685
789
788
755
760
775
745
735
805
800
730
725
ISLAND
720
665
715
GULF OF A
650
Puget Bay
645
Port Bainbridge
Prince of Wales Pass
679
778
710
MONTAGUE
Patton Bay
705
700
787
K 13

FIGURE 59. Spawning grounds of sockeye salmon in Central Alaska (Prince William Sound).

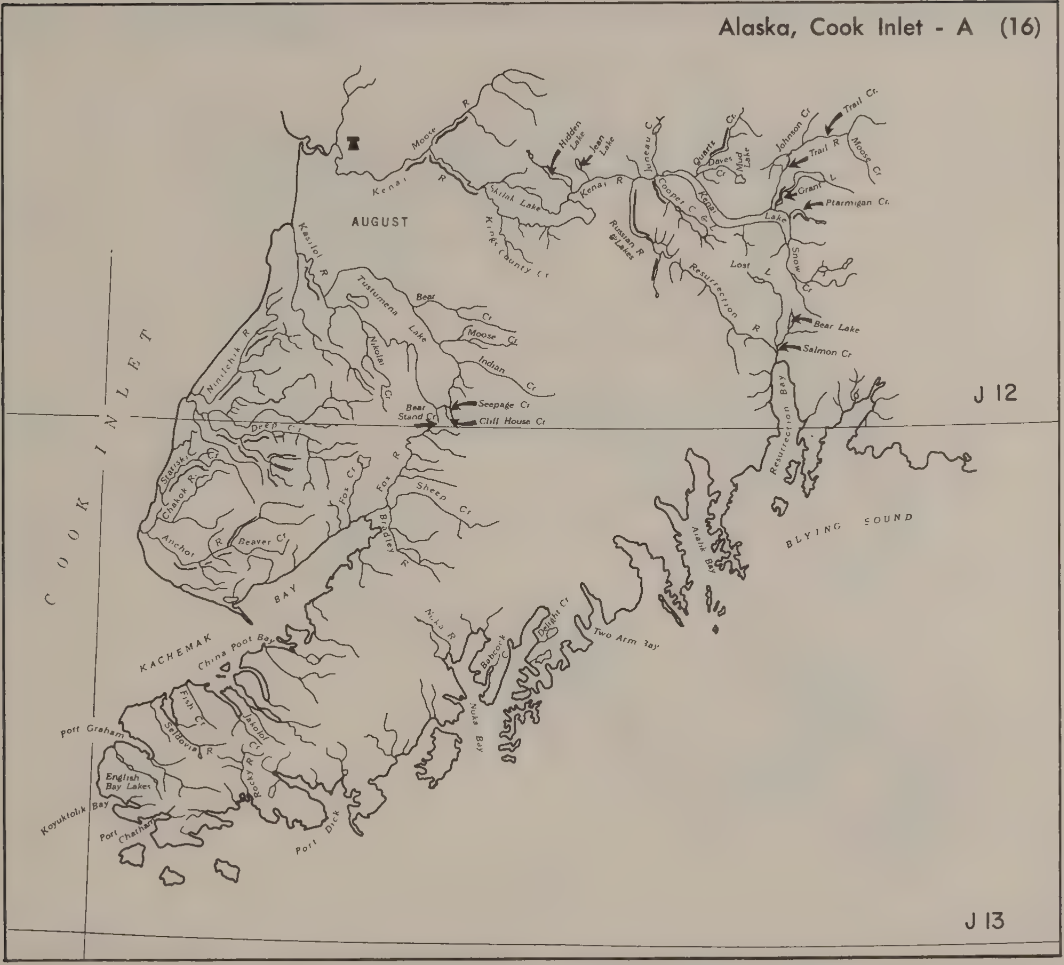
Alaska, Cook Inlet - A (16)
AUGUST
Moose R
Kenai R
Skilak Lake
Kings County Cr
Hidden Lake
Jean Lake
Juneau C
Kenai R
Russian R & Lakes
Coopers C
Quartz Cr
Daves Cr
Mud Lake
Kenai Lake
Johnson Cr
Trail Cr.
Trail R
Moose Cr
Grant L
Ptarmigan Cr.
Snow Cr
Lost L
Resurrection R
Bear Lake
Salmon Cr
Resurrection Bay
J 12
Kasilof R
Tustumena Lake
Bear Cr
Moose Cr
Indian Cr
Nikolai Cr
Seepage Cr
Bear Stand Cr
Cliff House Cr
Ninilchik R
Deep Cr
Stariski Cr
Chakok R
Anchor R
Beaver Cr
Fox Cr
Fox R
Sheep Cr
Bradley R
COOK INLET
KACHEMAK BAY
China Poot Bay
Port Graham
Fish Cr
Seldovia R
Jakolof Cr
Rocky R
English Bay Lakes
Koyuktolik Bay
Port Chatham
Port Dick
Nuka R
Babcock Cr
Nuka Bay
Delight Cr
Two Arm Bay
Aialik Bay
BLYING SOUND
J 13

FIGURE 60. Spawning grounds of chinook salmon in Central Alaska (Cook Inlet-A).

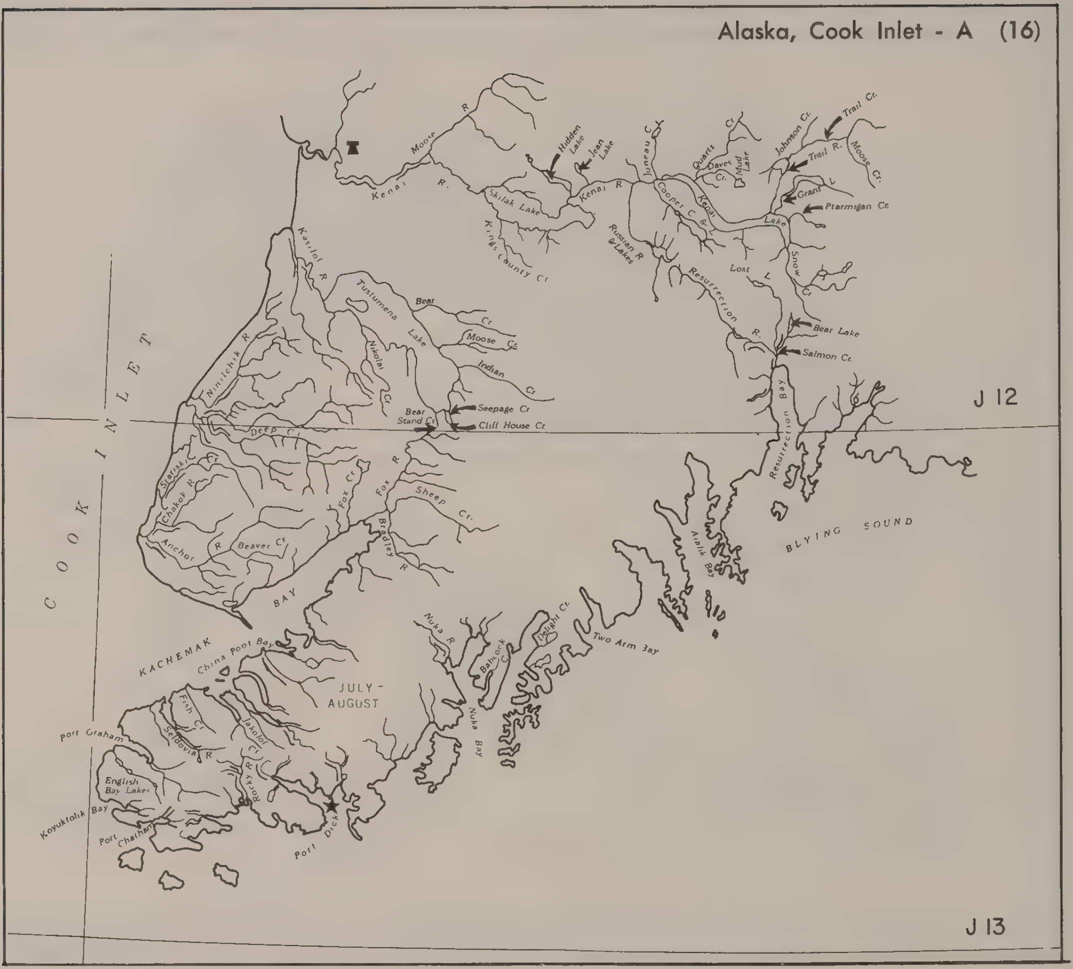
Alaska, Cook Inlet - A (16)
COOK INLET
Moose R
Kenai R.
Hidden Lake
Jean Lake
Skilak Lake
Kenai R
Juneau C
Quartz Cr
Daves Cr.
Mud Lake
Johnson Cr.
Trail Cr.
Trail R.
Moose Cr.
Grant L
Ptarmigan Cr.
Cooper C & L
Kenai Lake
Kings County Cr
Russian R & Lakes
Resurrection R.
Lost L
Snow Cr
Bear Lake
Salmon Cr.
Kasilof R
Tustumena Lake
Bear Cr
Moose Cr.
Indian Cr
Nikolai Cr.
Ninilchik R
Seepage Cr
Bear Stand Cr
Cliff House Cr
Deep Cr
Stariski Cr
Chakok R
Anchor R
Beaver Cr
Fox Cr
Fox R
Sheep Cr.
Bradley R
Resurrection Bay
J 12
BLYING SOUND
Aialik Bay
KACHEMAK BAY
China Poot Bay
JULY - AUGUST
Nuka R
Babcock Cr
Delight Cr.
Two Arm Bay
Nuka Bay
Fish Cr
Seldovia R
Jakolof Cr
Rocky R
Port Graham
English Bay Lakes
Koyuktolik Bay
Port Chatham
Port Dick
J 13

Figure 61. Spawning grounds of chum salmon in Central Alaska (Cook Inlet-A).

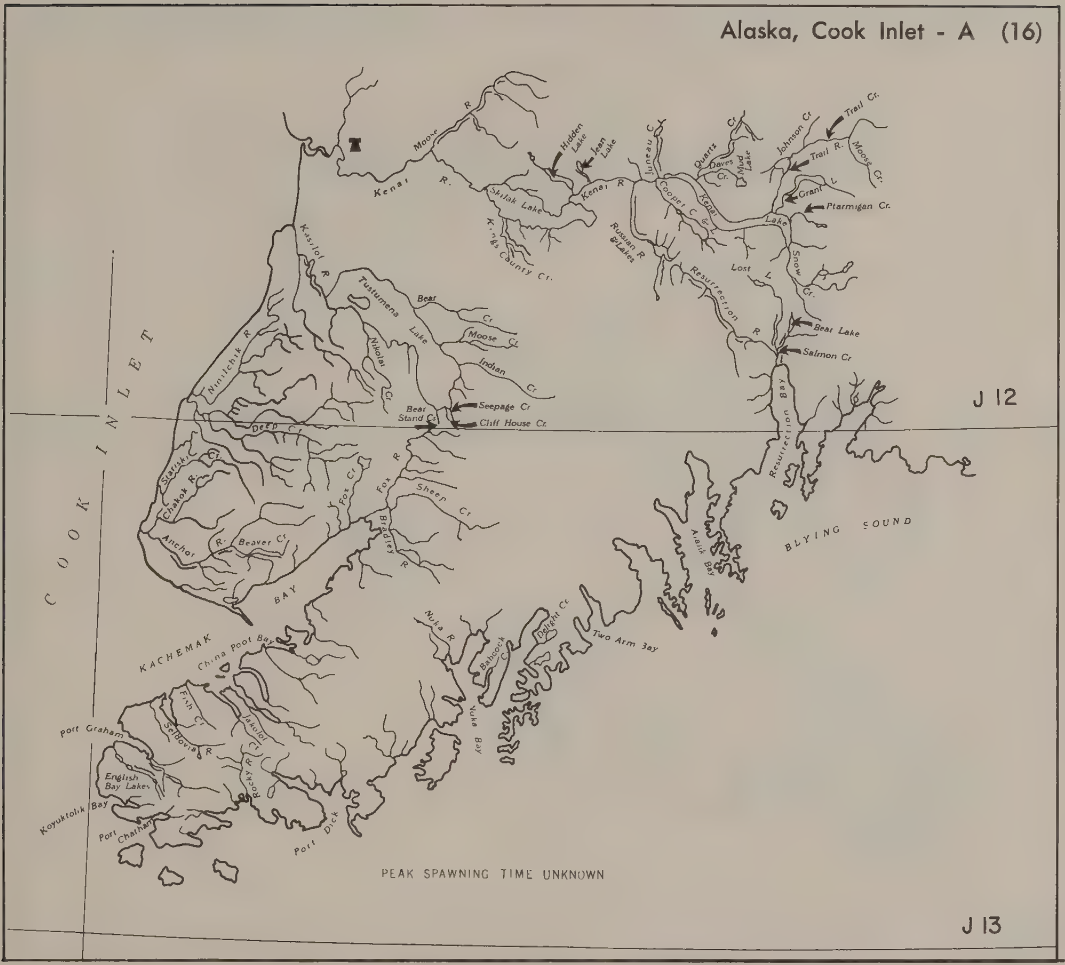
Alaska, Cook Inlet - A (16)
Moose R
Kenai R.
Hidden Lake
Jean Lake
Juneau C.
Quartz Cr.
Daves Cr.
Mud Lake
Johnson Cr.
Trail Cr.
Trail R.
Moose Cr.
Grant L
Ptarmigan Cr.
Skilak Lake
Kenai R
Cooper C.
Kenai Lake
Kings County Cr.
Russian R & Lakes
Resurrection R
Lost L
Snow Cr.
Bear Lake
Salmon Cr
Kasilof R
Tustumena Lake
Bear Cr.
Moose Cr.
Indian Cr.
Nikolai Cr.
Ninilchik R
Bear Stand Cr.
Seepage Cr
Cliff House Cr.
J 12
Deep Cr.
Stariski Cr.
Chakok R.
Fox Cr.
Fox R
Sheep Cr.
Resurrection Bay
BLYING SOUND
Aialik Bay
Anchor R.
Beaver Cr.
Bradley R
COOK INLET
KACHEMAK BAY
China Poot Bay
Nuka R
Babcock Cr.
Delight Cr.
Two Arm Bay
Fish Cr.
Seldovia R
Jakolof
Port Graham
English Bay Lakes
Rocky R
Nuka Bay
Koyuktolik Bay
Port Chatham
Port Dick
PEAK SPAWNING TIME UNKNOWN
J 13

FIGURE 62. Spawning grounds of coho salmon in Central Alaska (Cook Inlet-A).

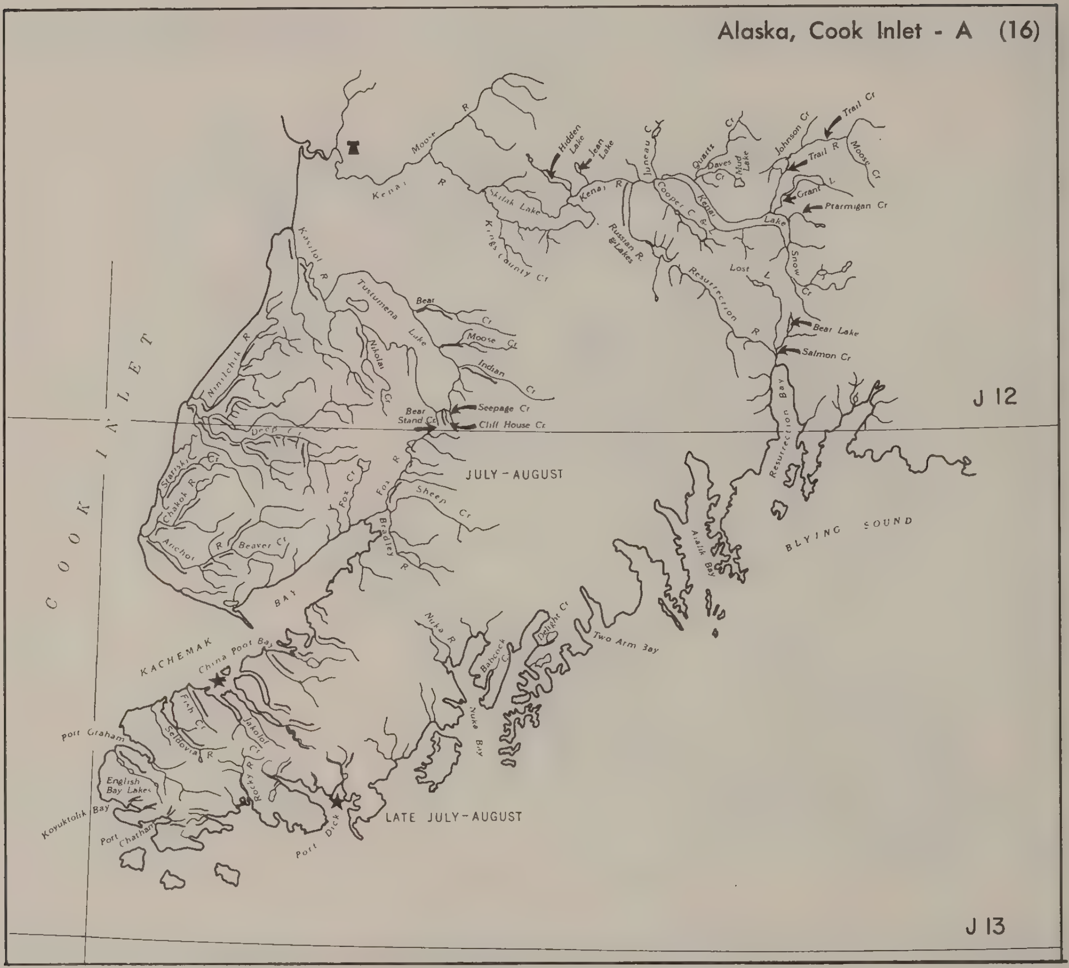
Alaska, Cook Inlet - A (16)
Moose R
Kenai R
Hidden Lake
Jean Lake
Juneau C
Quartz Cr
Daves Cr
Mud Lake
Johnson Cr
Trail Cr
Trail R
Moose Cr
Grant L
Ptarmigan Cr
Skilak Lake
Kenai R
Kings County Cr
Russian R. & Lakes
Cooper C & L
Kenai Lake
Lost L
Snow Cr
Resurrection R
Bear Lake
Salmon Cr
Kasilof R
Tustumena Lake
Bear Cr
Moose Cr
Indian Cr
Nikolai Cr
Seepage Cr
Bear Stand Cr
Cliff House Cr
Resurrection Bay
J 12
COOK INLET
Ninilchik R
Deep Cr
Stariski Cr
Chakok R
Anchor R
Beaver Cr
Fox Cr
Fox R
Sheep Cr
Bradley R
JULY - AUGUST
BLYING SOUND
Aialik Bay
KACHEMAK BAY
China Poot Bay
Nuka R
Babcock C
Delight Cr
Two Arm Bay
Fish Cr
Seldovia R
Jakolof Cr
Rocky R
Nuka Bay
Port Graham
English Bay Lakes
Koyuktolik Bay
Port Chatham
Port Dick
LATE JULY - AUGUST
J 13

Figure 63. Spawning grounds of pink salmon in Central Alaska (Cook Inlet-A).

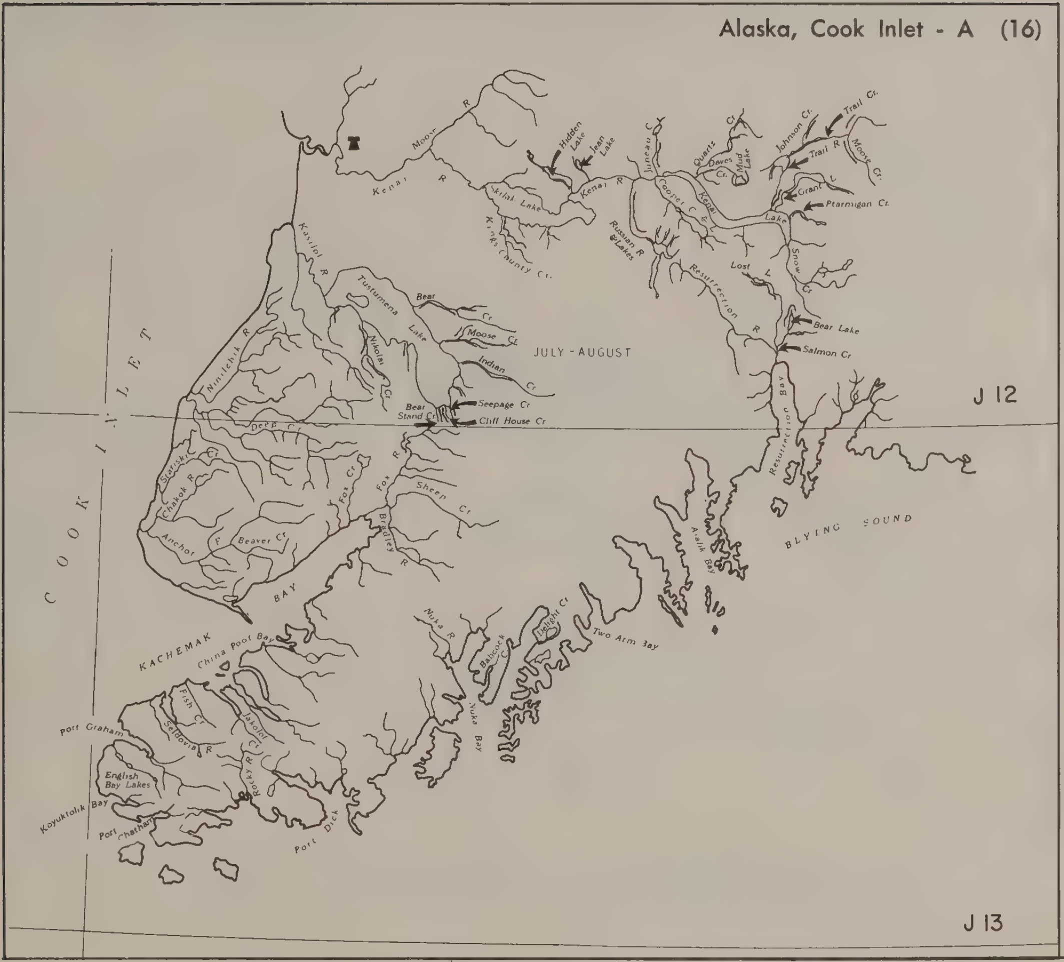
Alaska, Cook Inlet - A (16)
Moose R
Kenai R
Hidden Lake
Jean Lake
Skilak Lake
Kenai R
Kings County Cr.
Juneau Cr.
Quartz Cr.
Daves Cr.
Mud Lake
Johnson Cr.
Trail Cr.
Trail R
Moose Cr.
Grant L
Ptarmigan Cr.
Cooper C & L
Kenai Lake
Russian R & Lakes
Lost L
Snow Cr.
Resurrection R
Bear Lake
Salmon Cr.
Kasilof R
Tustumena Lake
Bear Cr.
Moose Cr.
Indian Cr.
Nikolai Cr.
JULY - AUGUST
Ninilchik R
Bear Stand Cr.
Seepage Cr.
Chill House Cr.
J 12
Deep Cr.
Stariski Cr.
Chakok R
Fox Cr.
Fox R
Sheep Cr.
Anchor R
Beaver Cr.
Bradley R
COOK INLET
Resurrection Bay
BLYING SOUND
Aialik Bay
BAY
KACHEMAK
China Poot Bay
Nuka R
Babcock Cr.
Delight Cr.
Two Arm Bay
Nuka Bay
Port Graham
Fish Cr.
Seldovia R
Jakolof Cr.
Rocky R
English Bay Lakes
Koyuktolik Bay
Port Chatham
Port Dick
J 13

Figure 64. Spawning grounds of sockeye salmon in Central Alaska (Cook Inlet-A).

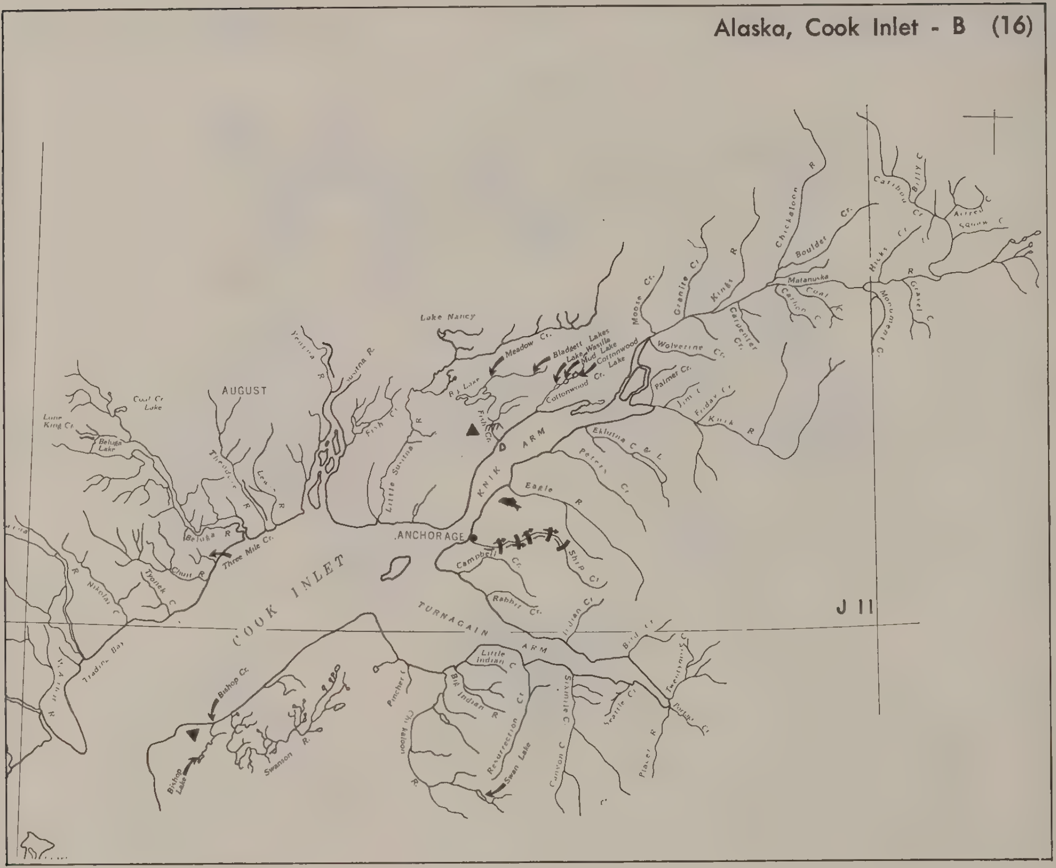
Alaska, Cook Inlet - B (16)
AUGUST
Coal Cr. Lake
Beluga Lake
Beluga R
Three Mile Cr.
Chuit R
Tyonek C
Nikolai C
Theodore R
Lewis R
Yentna R
Susitna R
Fish Cr.
Little Susitna R
Lake Nancy
Meadow Cr.
Bladgett Lakes
Lake Wasilla
Mud Lake
Cottonwood Lake
Cottonwood Cr.
Fish Cr.
KNIK ARM
ANCHORAGE
COOK INLET
Eklutna C & L
Peters Cr.
Eagle R
Campbell Cr.
Ship Cr.
Rabbit Cr.
TURNAGAIN ARM
Indian Cr.
Bird Cr.
Little Indian C
Big Indian R
Resurrection Cr.
Swan Lake
Sixmile C
Canyon C
Seattle Cr.
Placer R
Portage Cr.
Twentymile C
Pencher C
Chickaloon R
Bishop Cr.
Bishop Lake
Swanson R
Trading Bay
Moose Cr.
Granite Cr.
Kings R
Chickaloon R
Boulder Cr.
Carpenter Cr.
Wolverine Cr.
Palmer Cr.
Jim C
Friday Cr.
Knik R
Matanuska R
Coal C
Caribou Cr.
Billy C
Hicks Cr.
Alfred C
Squaw C
Monument C
Gravel C
J 11

FIGURE 65. Spawning grounds of chinook salmon in Central Alaska (Cook Inlet-B).

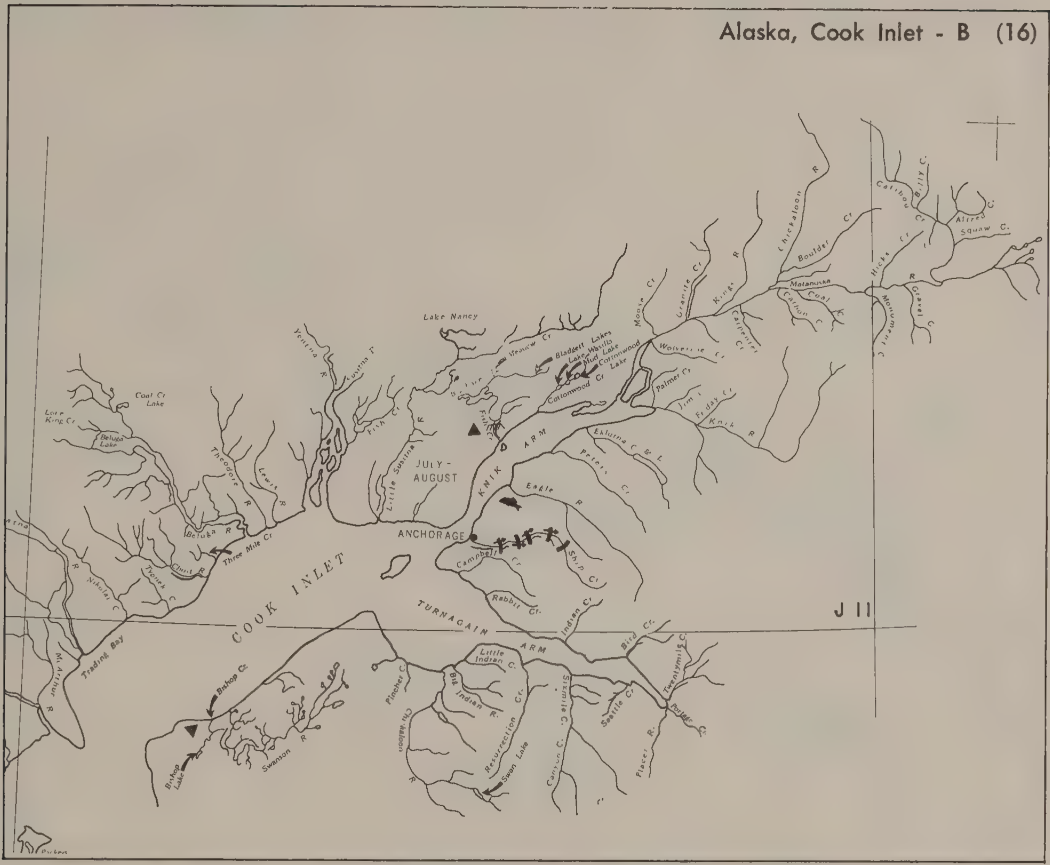
Alaska, Cook Inlet - B (16)
Lake Nancy
Yentna R
Susitna R
Meadow Cr
Bladgett Lakes
Lake Wasilla
Mud Lake
Cottonwood Lake
Cottonwood Cr
Fish Cr
Fish Cr
Little Susitna R
JULY - AUGUST
KNIK ARM
ANCHORAGE
Coal Cr Lake
Lone King Cr
Beluga Lake
Theodore R
Lewis R
Beluga R
Three Mile Cr
Chuit R
Tyonek C
Nikolai C
R
Mc Arthur R
Trading Bay
COOK INLET
TURNAGAIN ARM
Bishop Cr
Bishop Lake
Swanson R
Pincher C
Chickaloon R
Little Indian C.
Big Indian R.
Resurrection Cr.
Swan Lake
Sixmile C.
Canyon C.
Seattle Cr
Placer R.
Portage C.
Twentymile C.
Bird Cr.
Indian Cr
Rabbit Cr.
Campbell Cr
Ship Cr
Eagle R
Peters Cr
Eklutna C & L
Knik R
Friday Cr
Jim C
Palmer Cr
Wolverine Cr
Moose Cr
Granite Cr
Kings R
Carpenter Cr
Chickaloon R
Boulder Cr
Matanuska
Coal C
Carbon C
Caribou Cr
Billy C.
Alfred C.
Squaw C.
Hicks Cr
R
Monument C
Gravel C
J 11

FIGURE 66. Spawning grounds of chum salmon in Central Alaska (Cook Inlet-B).

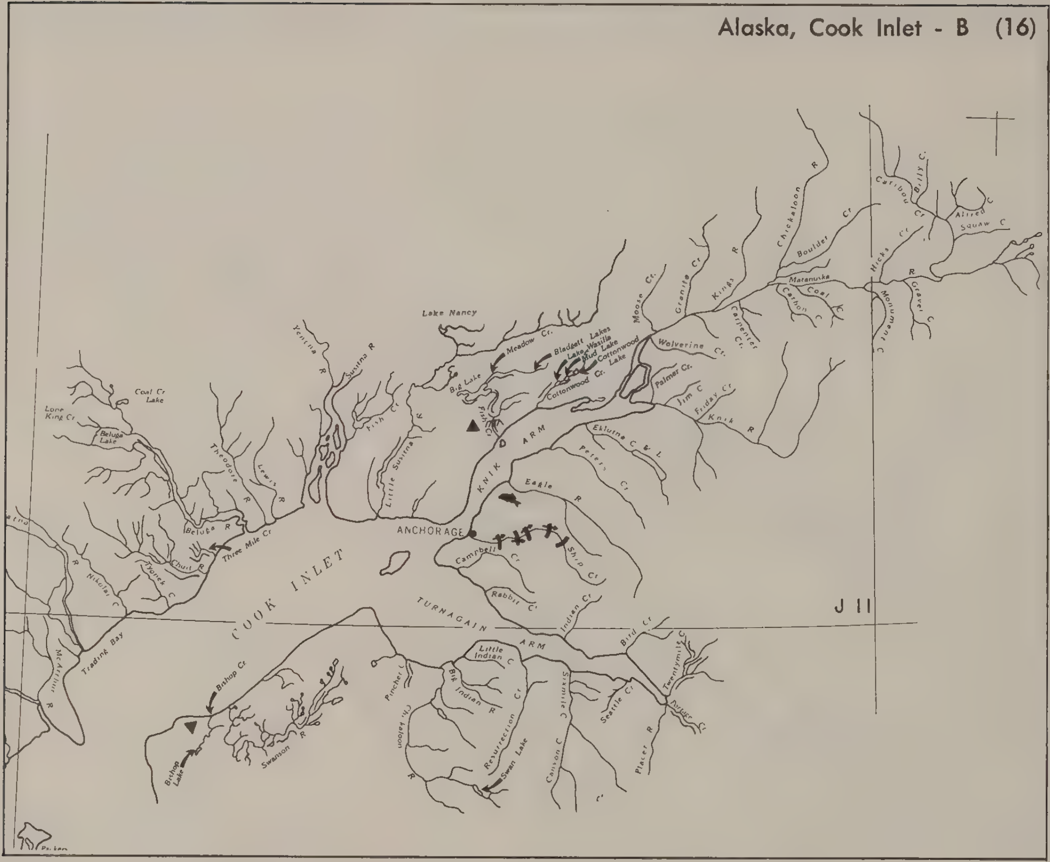
Alaska, Cook Inlet - B (16)
Lake Nancy
Yentna R
Susitna R
Meadow Cr.
Bladgett Lakes
Lake Wasilla
Mud Lake
Cottonwood Lake
Cottonwood Cr.
Big Lake
Fish Cr
Coal Cr Lake
Lone King Cr
Beluga Lake
Theodore R
Lewis R
Fish Cr
Little Susitna R
Beluga R
Three Mile Cr
Chuit R
Tyonek C
Nikolai C
R
McArthur R
Trading Bay
COOK INLET
ANCHORAGE
KNIK ARM
Eagle R
Campbell Cr
Ship Cr
Rabbit Cr
TURNAGAIN ARM
Little Indian C
Big Indian R
Resurrection Cr
Pincher C
Chickaloon R
Swan Lake
Bishop Cr
Bishop Lake
Swanson R
Sixmile C
Canyon C
Indian Cr
Bird Cr
Twentymile C
Seattle Cr
Placer R
Portage Cr
Moose Cr.
Granite Cr
Kings R
Chickaloon R
Boulder Cr
Carpenter Cr.
Matanuska R
Coal C
Carbon C
Caribou Cr
Billy C.
Alfred C
Squaw C
Hicks Cr
Monument C
Gravel C
Wolverine Cr.
Palmer Cr.
Jim C
Friday Cr
Knik R
Eklutna C & L
Peters Cr
J 11

FIGURE 67. Spawning grounds of coho salmon in Central Alaska (Cook Inlet-B).

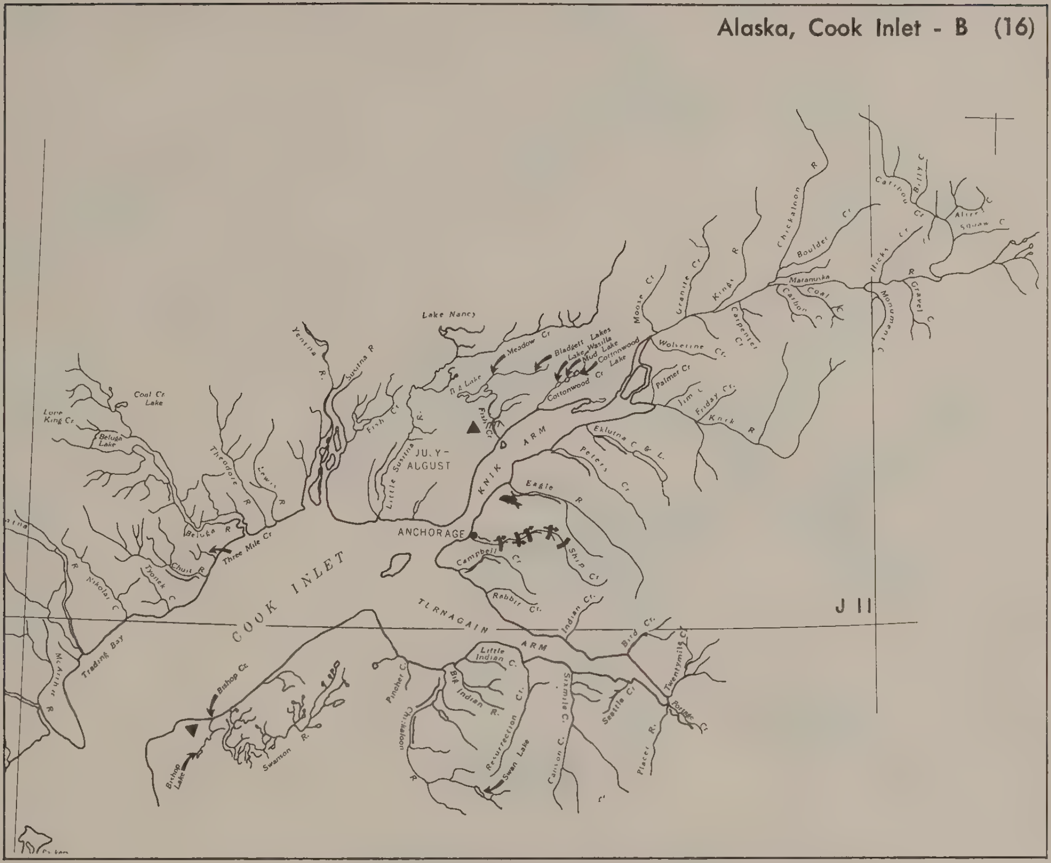
Alaska, Cook Inlet - B (16)
Lake Nancy
Yentna R.
Susitna R
Meadow Cr
Bladgett Lakes
Lake Wasilla
Mud Lake
Cottonwood Lake
Cottonwood Cr
B A Lake
Fish Cr
Fish Cr
Susitna R.
Little Susitna
JULY-AUGUST
Coal Cr. Lake
Lone King Cr.
Beluga Lake
Theodore R
Lewis R
Beluga R
Three Mile Cr
Chuit R
Tyonek C
Nikolai C
R
McArthur R
Trading Bay
COOK INLET
ANCHORAGE
KNIK ARM
Eagle R
Eklutna C & L.
Peters Cr
Campbell Cr
Ship Cr
Rabbit Cr.
Indian Cr.
TURNAGAIN ARM
Bird Cr.
Twentymile C
Portage C
Little Indian C.
Big Indian R.
Resurrection Cr.
Swan Lake
Sixmile C.
Canyon C.
Seattle Cr
Placer R.
Pincher C.
Chickaloon R
Bishop Cr.
Bishop Lake
Swanson R.
Wolverine Cr.
Palmer Cr
Jim C
Friday Cr.
Knik R
Moose Cr
Granite Cr
Kings R
Carpenter Cr
Chickalnon R
Boulder Cr
Matanuska R
Coal C
Carbon C
Caribou Cr
Billy C
Alfred C
Squaw C
Hicks Cr
Monument C
Gravel C
J II

FIGURE 68. Spawning grounds of pink salmon in Central Alaska (Cook Inlet-B).

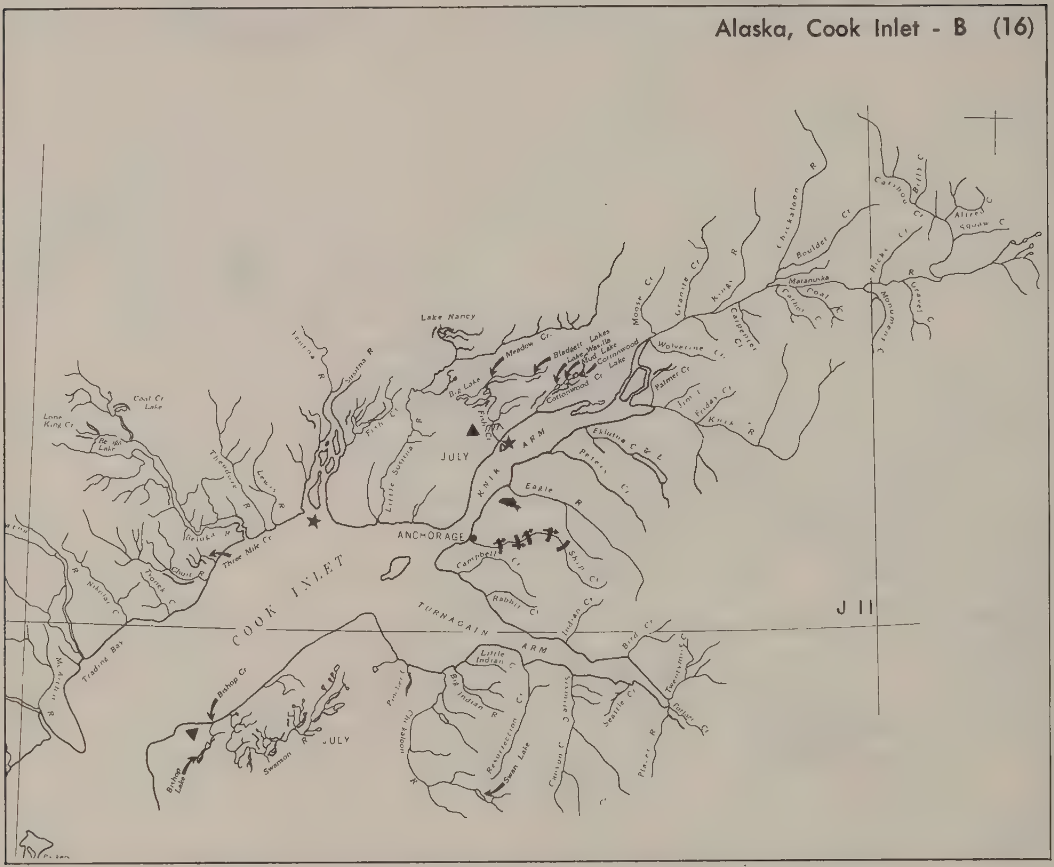
Alaska, Cook Inlet - B (16)
Lake Nancy
Yentna R
Susitna R
Meadow Cr.
Bladgett Lakes
Lake Wasilla
Mud Lake
Cottonwood Lake
Cottonwood Cr
Big Lake
Fish Cr
Fish Cr
Little Susitna R
JULY
KNIK ARM
Coal Cr Lake
Lone King Cr
Beluga Lake
Theodore R
Lewis R
Beluga R
Three Mile Cr
Chuit R
Tyonek C
Nikolai C
Trading Bay
McArthur R
ANCHORAGE
COOK INLET
Campbell Cr
Ship Cr
Rabbit Cr
Eagle R
Peters Cr
Eklutna C & L
TURNAGAIN ARM
Indian Cr
Bird Cr
Twentymile C
Portage Cr
Placer R
Seattle Cr
Sixmile C
Canyon C
Resurrection Cr
Swan Lake
Big Indian R
Little Indian C
Chickaloon R
Bishop Cr
Bishop Lake
Swanson R
JULY
Moose Cr
Granite Cr
Kings R
Carpenter Cr
Wolverine Cr
Palmer Cr
Jim C
Friday Cr
Knik R
Chickaloon R
Boulder Cr
Matanuska R
Coal C
Caribou Cr
Billy C
Alfred C
Squaw C
Hicks Cr
Monument C
Gravel C
J II

FIGURE 69. Spawning grounds of sockeye salmon in Central Alaska (Cook Inlet-B).

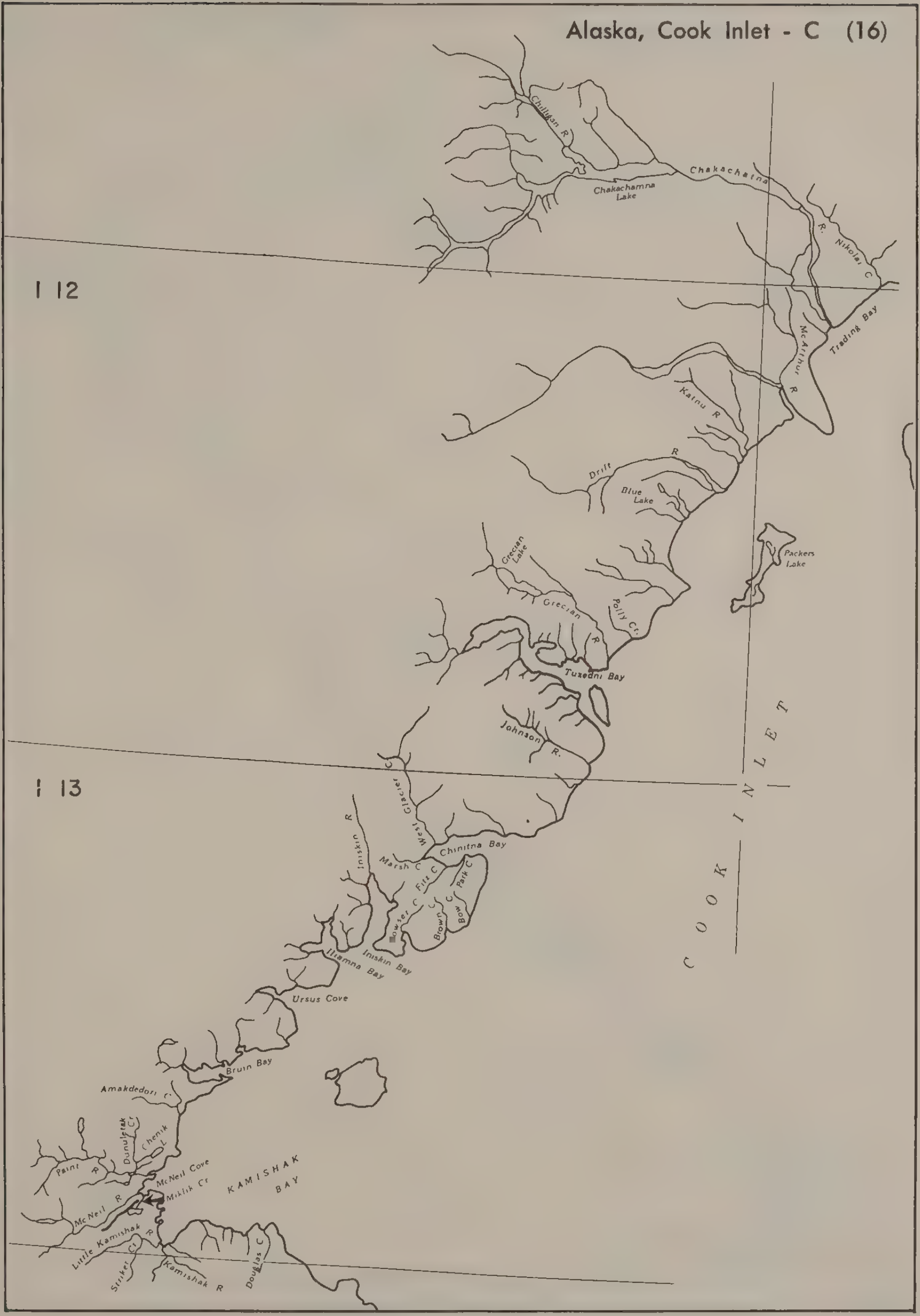
Alaska, Cook Inlet - C (16)
I 12
I 13
Chilligan R
Chakachatna R.
Chakachamna Lake
Nikolai C
Trading Bay
McArthur R
Katnu R
Drift R
Blue Lake
Packers Lake
Grecian Lake
Grecian R
Polly Cr.
Tuxedni Bay
Johnson R.
COOK INLET
West Glacier C
Iniskin R
Chinitna Bay
Marsh C
Fitz C
Park C
Bowser C
Brown C
Bow C
Iniskin Bay
Iliamna Bay
Ursus Cove
Bruin Bay
Amakdedori C
Dunuletak Cr
Chenik L
Paint R
McNeil Cove
Mikfik Cr
KAMISHAK BAY
McNeil R
Little Kamishak R
Strike Cr
Kamishak R
Douglas C

FIGURE 70. Spawning grounds of chinook salmon in Central Alaska (Cook Inlet-C).

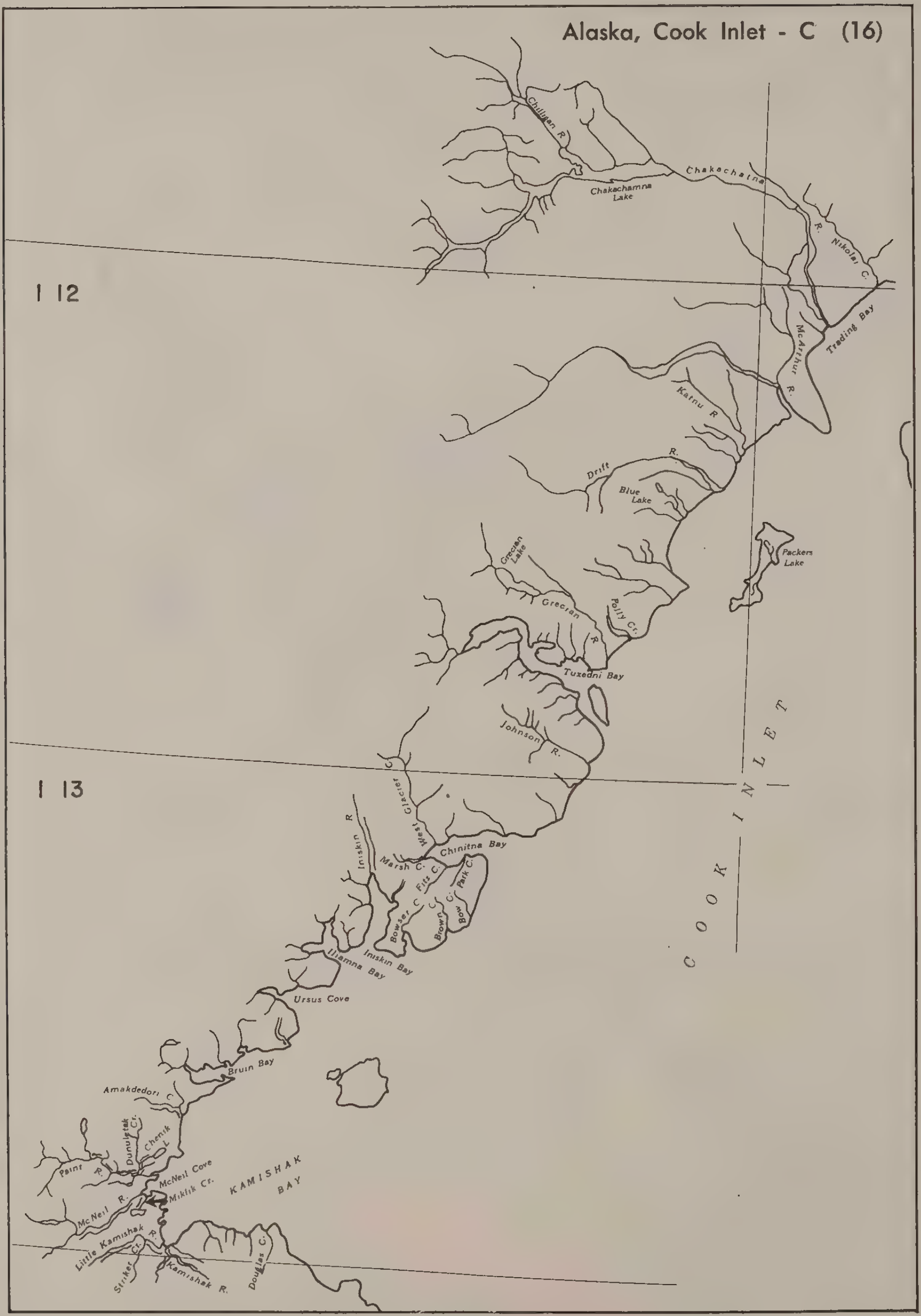
Alaska, Cook Inlet - C (16)
I 12
I 13
Chilligan R.
Chakachatna
Chakachamna Lake
R.
Nikolai C.
Trading Bay
McArthur R.
Katnu R.
Drift R.
Blue Lake
Packers Lake
Grecian Lake
Grecian R.
Polly Cr.
Tuxedni Bay
Johnson R.
COOK INLET
West Glacier C.
Iniskin R.
Chinitna Bay
Marsh C.
Fitz C.
Bowser C.
Brown C.
Bow C.
Park C.
Iniskin Bay
Iliamna Bay
Ursus Cove
Bruin Bay
Amakdedori C.
Dunuletak Cr.
Chenik L.
Paint R.
McNeil Cove
Miklik Cr.
KAMISHAK BAY
McNeil R.
Little Kamishak R.
Striker Cr.
Kamishak R.
Douglas C.

Figure 71. Spawning grounds of chum salmon in Central Alaska (Cook Inlet-C).

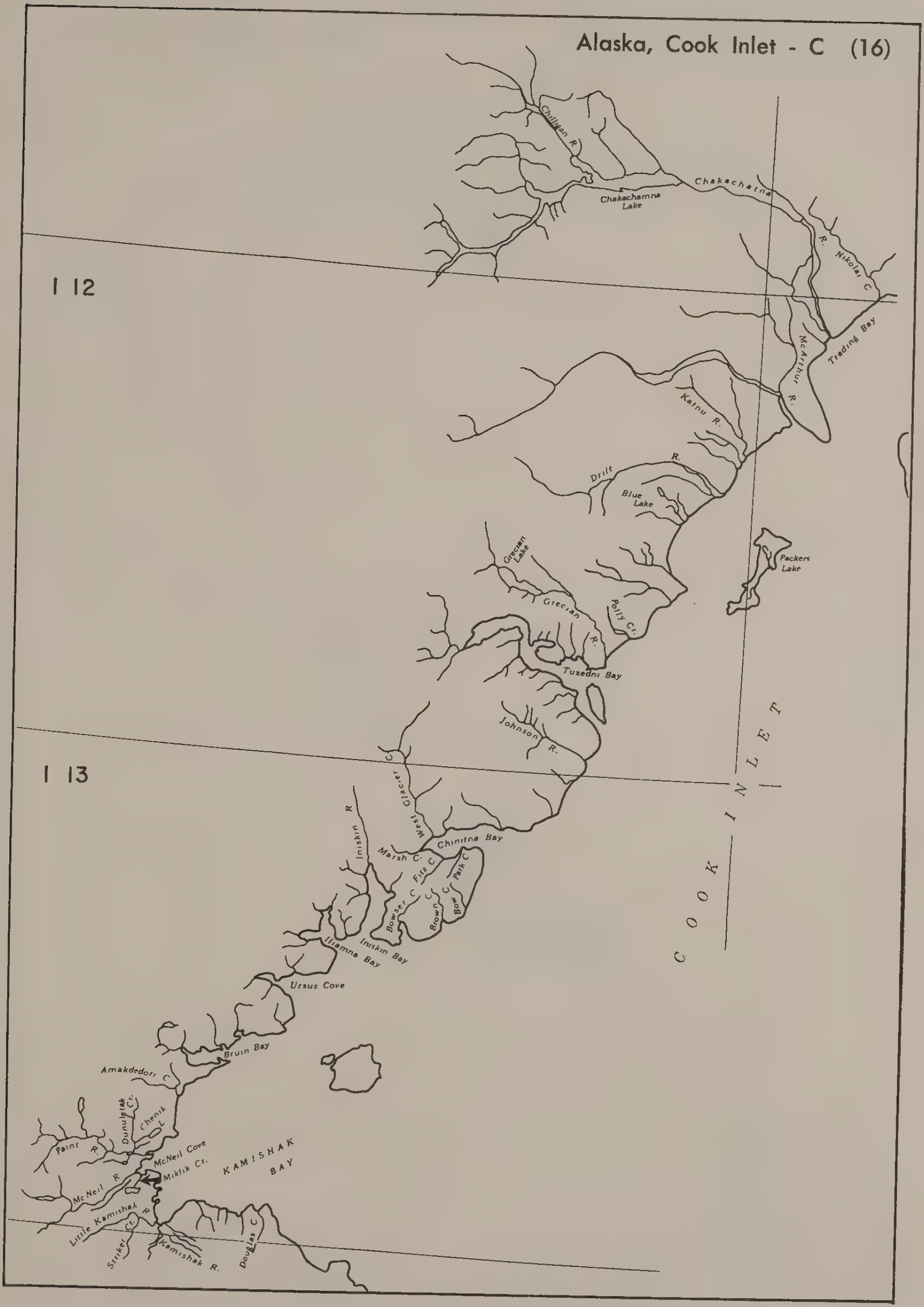
Alaska, Cook Inlet - C (16)
I 12
I 13
Chilligan R.
Chakachatna
Chakachamna Lake
R. Nikolai C
Trading Bay
McArthur R.
Katnu R.
Drift R.
Blue Lake
Packers Lake
Grecian Lake
Grecian R.
Polly Cr.
Tuxedni Bay
Johnson R.
West Glacier C
Iniskin R
Chinitna Bay
Marsh C.
Fitz C
Park C
Bowser C
Brown C
Bow
Iniskin Bay
Iliamna Bay
Ursus Cove
Bruin Bay
Amakdedori C
Dunuletak Cr.
Chenik L
Paint R.
McNeil Cove
Miklik Cr.
KAMISHAK BAY
McNeil R
Little Kamishak R
Strike Cr.
Kamishak R.
Douglas C
COOK INLET

Figure 72. Spawning grounds of coho salmon in Central Alaska (Cook Inlet-C).

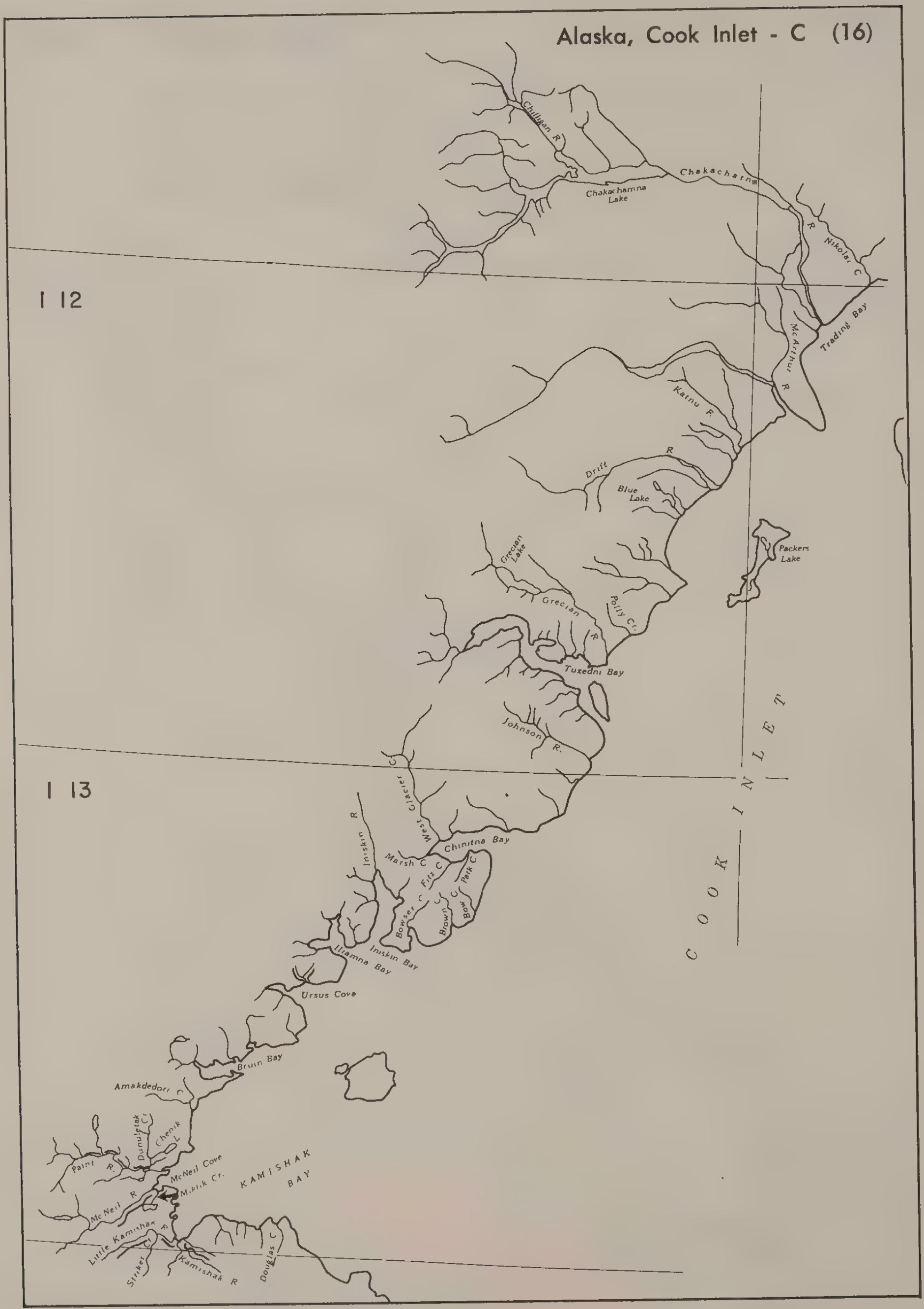
Alaska, Cook Inlet - C (16)
I 12
I 13
Chilligan R
Chakachamna Lake
Chakachatna
Nikolai C
R
Trading Bay
McArthur R
Katnu R
Drift R
Blue Lake
Packers Lake
Grecian Lake
Grecian R
Polly Cr.
Tuxedni Bay
Johnson R.
West Glacier C
Iniskin R
Chinitna Bay
Marsh C
Fitz C
Park C
Bowser C
Brown C
Bow C
Iniskin Bay
Iliamna Bay
Ursus Cove
Bruin Bay
Amakdedori C
Dunuletak Cr
Chenik L
Paint R.
McNeil Cove
Mikfik Cr.
McNeil R
Little Kamishak R
Strike Cr
Kamishak R
Douglas C
KAMISHAK BAY
COOK INLET

Figure 73. Spawning grounds of pink salmon in Central Alaska (Cook Inlet-C).

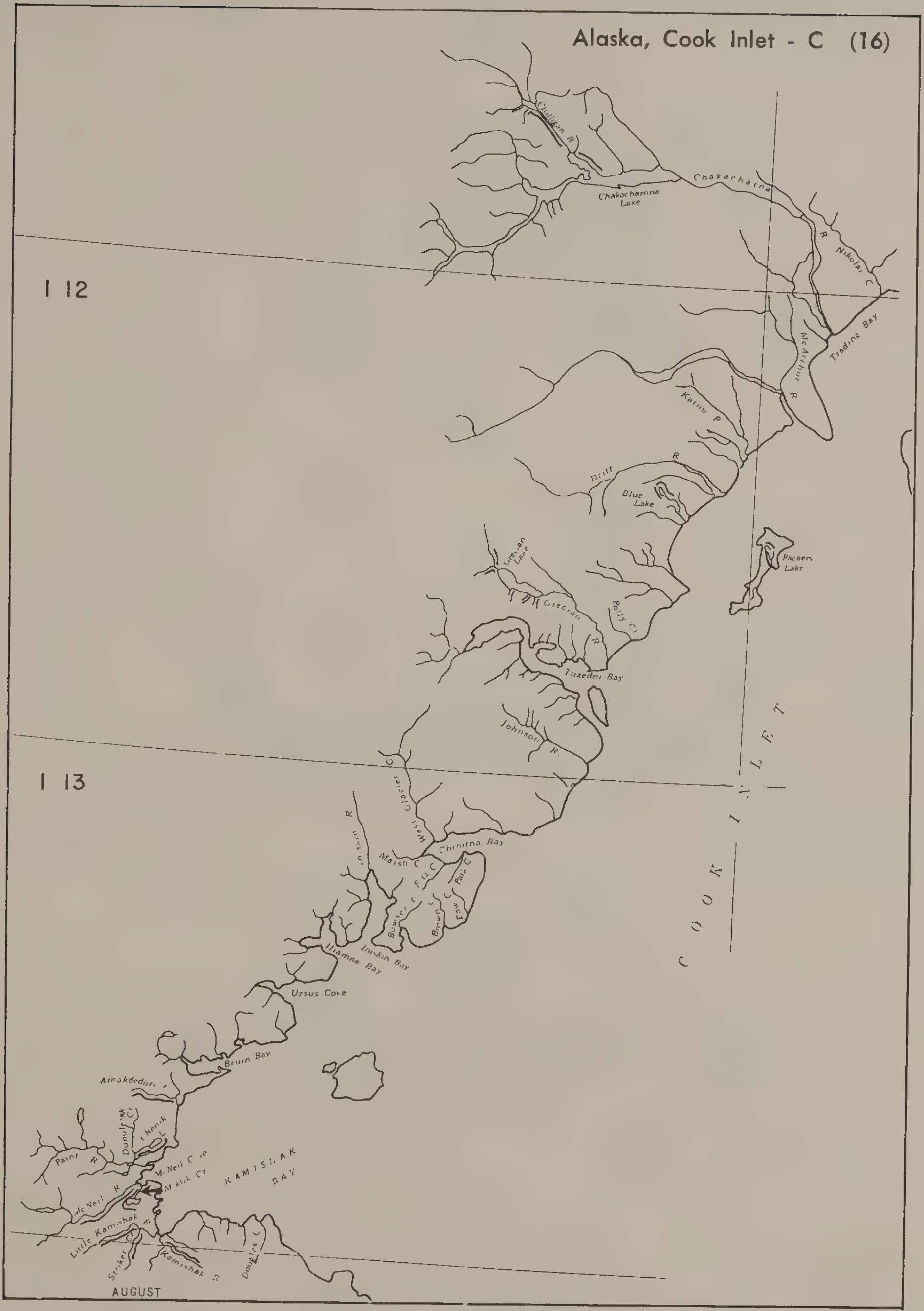
Alaska, Cook Inlet - C (16)
I 12
I 13
Chilligan R
Chakachamna Lake
Chakachatna
R
Nikolai C
Trading Bay
McArthur R
Katnu R
R
Drift
Blue Lake
Packers Lake
Crescent Lake
Crescent R
Polly Cr
Tuxedni Bay
Johnson R.
West Glacier C
Iniskin R
Chinitna Bay
Marsh C
Fitz C
Park C
Bowser C
Brown C
Bow
Iniskin Bay
Iliamna Bay
Ursus Cove
Bruin Bay
Amakdedori
Dunuletak Cr
Chenik L
Paint R
McNeil Cove
Mikfik Cr
KAMISHAK BAY
McNeil R
Little Kamishak R
Strike Cr
Kamishak R
Douglas C
COOK INLET
AUGUST

FIGURE 74. Spawning grounds of sockeye salmon in Central Alaska (Cook Inlet-C).

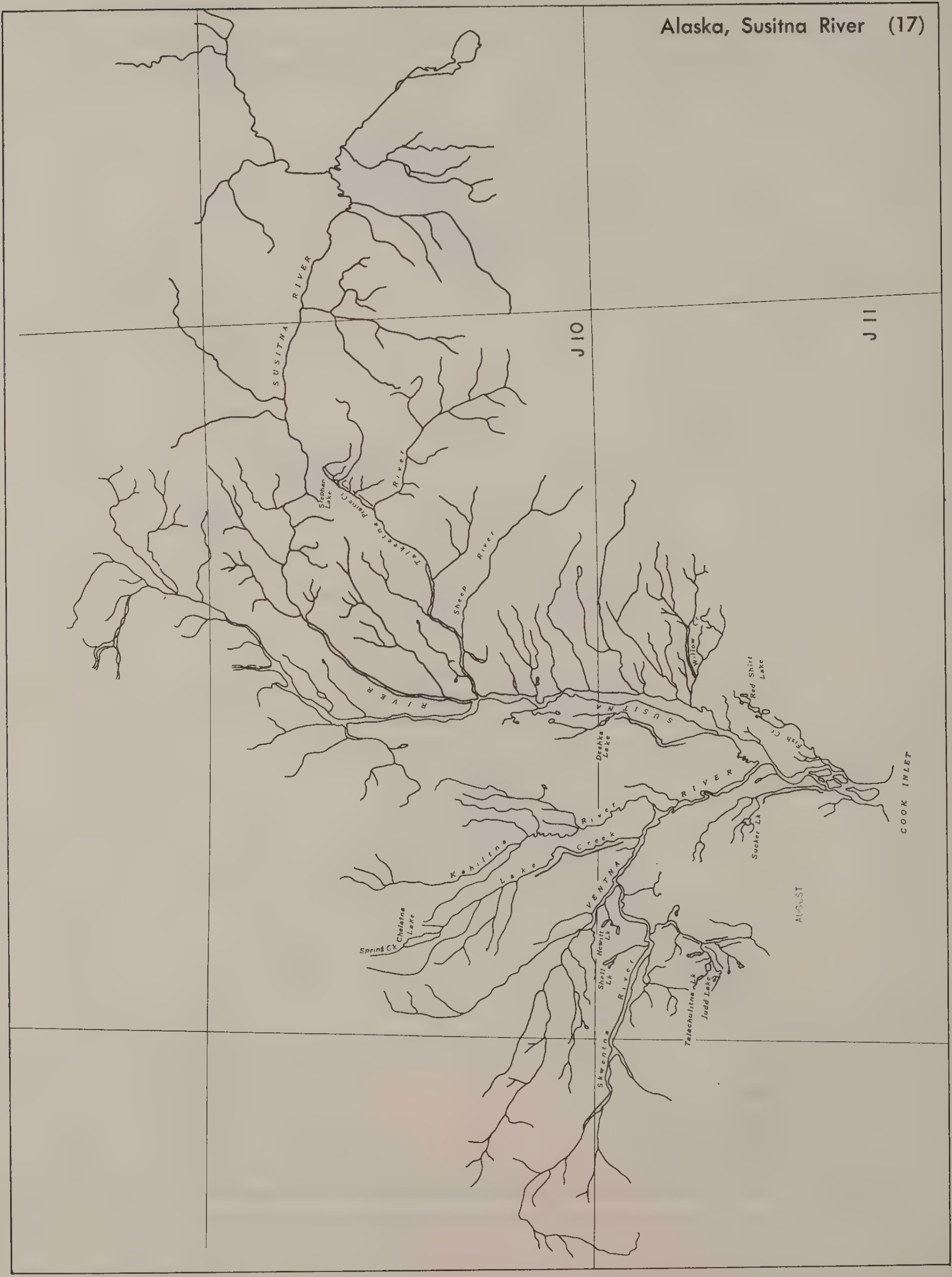
Alaska, Susitna River (17)
J10
J11
SUSITNA RIVER
Stephan Lake
Prairie Cr.
Talkeetna River
Sheep River
RIVER
Willow Cr
Red Shirt Lake
SUSITNA RIVER
Deshka Lake
Fish Cr
COOK INLET
Sucker Lk
AUGUST
Kahiltna River
Lake Creek
Chelatna Lake
Sprint Ck
VENTNA River
Hewitt Lk
Shell Lk
Talachulitna Lk
Judd Lake
Skwentna

FIGURE 75. Spawning grounds of chinook salmon in Central Alaska (Susitna River).

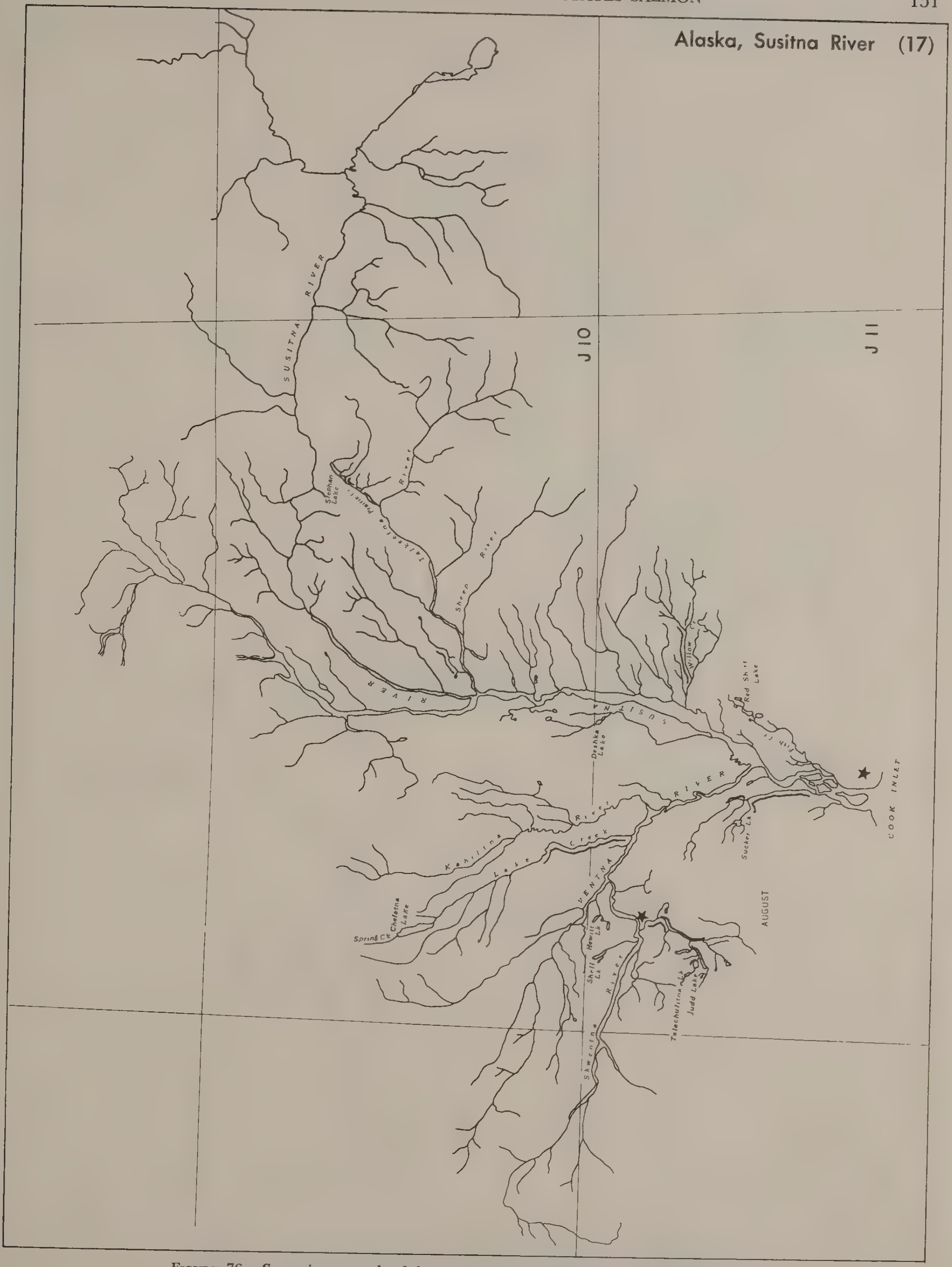
Alaska, Susitna River (17)
J 10
J 11
SUSITNA RIVER
Stephan Lake
Prairie Cr.
Talkeetna River
Sheep River
RIVER
Willow Cr.
Red Shirt Lake
SUSITNA
Deshka Lake
Fish Cr.
RIVER
COOK INLET
Sucker Lk
Kahiltna River
Lake Creek
YENTNA
Chelatna Lake
Spring Ck
Hewitt Lk
Shell Lk
River
Skwentna
Talachulitna Lk
Judd Lake
AUGUST

FIGURE 76. Spawning grounds of chum salmon in Central Alaska (Susitna River).

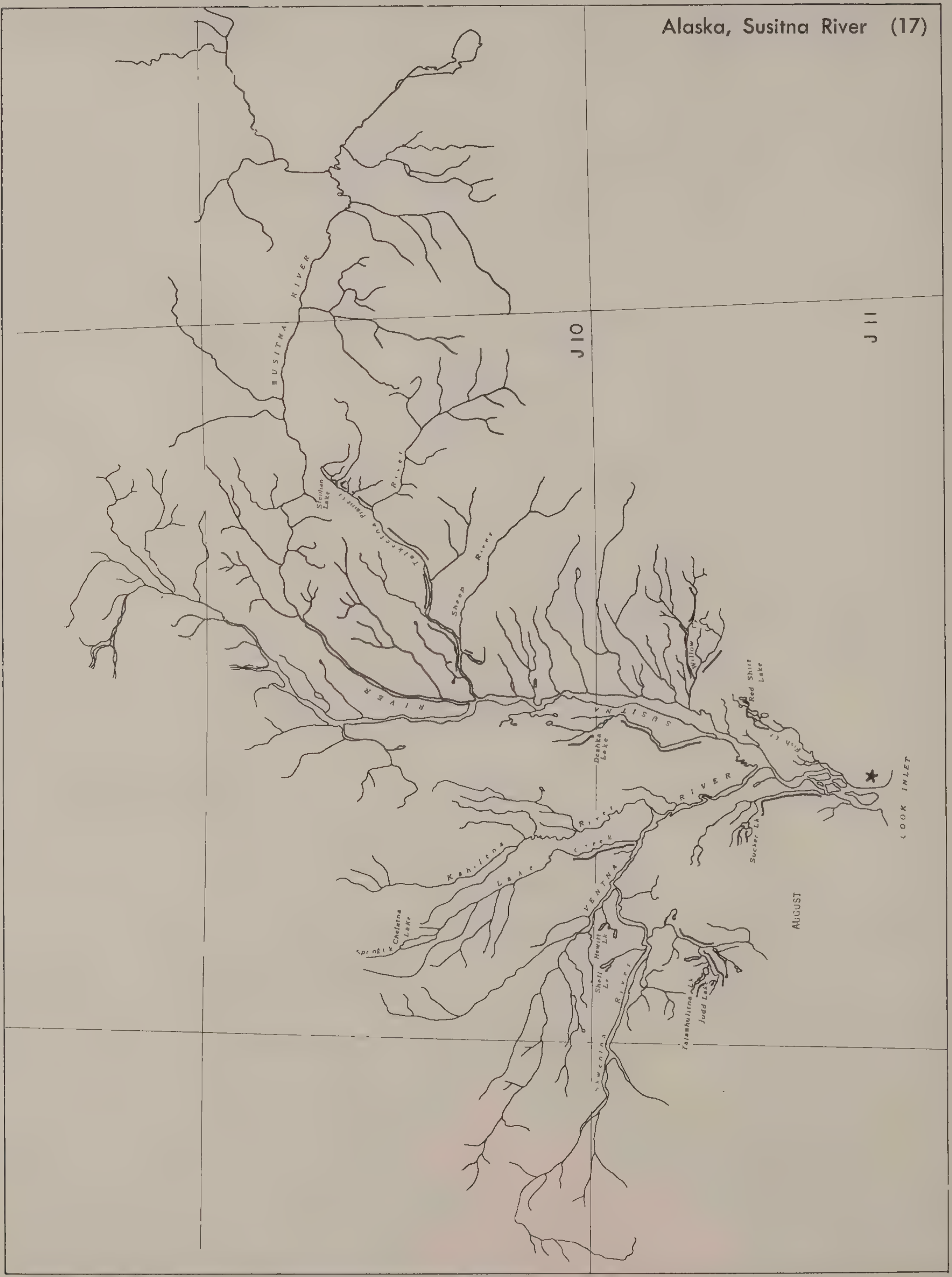
Alaska, Susitna River (17)
J10
J11
SUSITNA RIVER
Stephan Lake
Prairie Cr
Talkeetna River
Sheep River
RIVER
Willow Cr
Red Shirt Lake
SUSITNA
Deshka Lake
Fish Cr
RIVER
COOK INLET
River
Creek
Kahiltna
Lake
Chelatna Lake
Spring Ck
VENTNA
Hewitt Lk
Shell Lk
River
Skwentna
Sucker Lk
Talachulitna Lk
Judd Lake
AUGUST

Figure 77. Spawning grounds of coho salmon in Central Alaska (Susitna River).

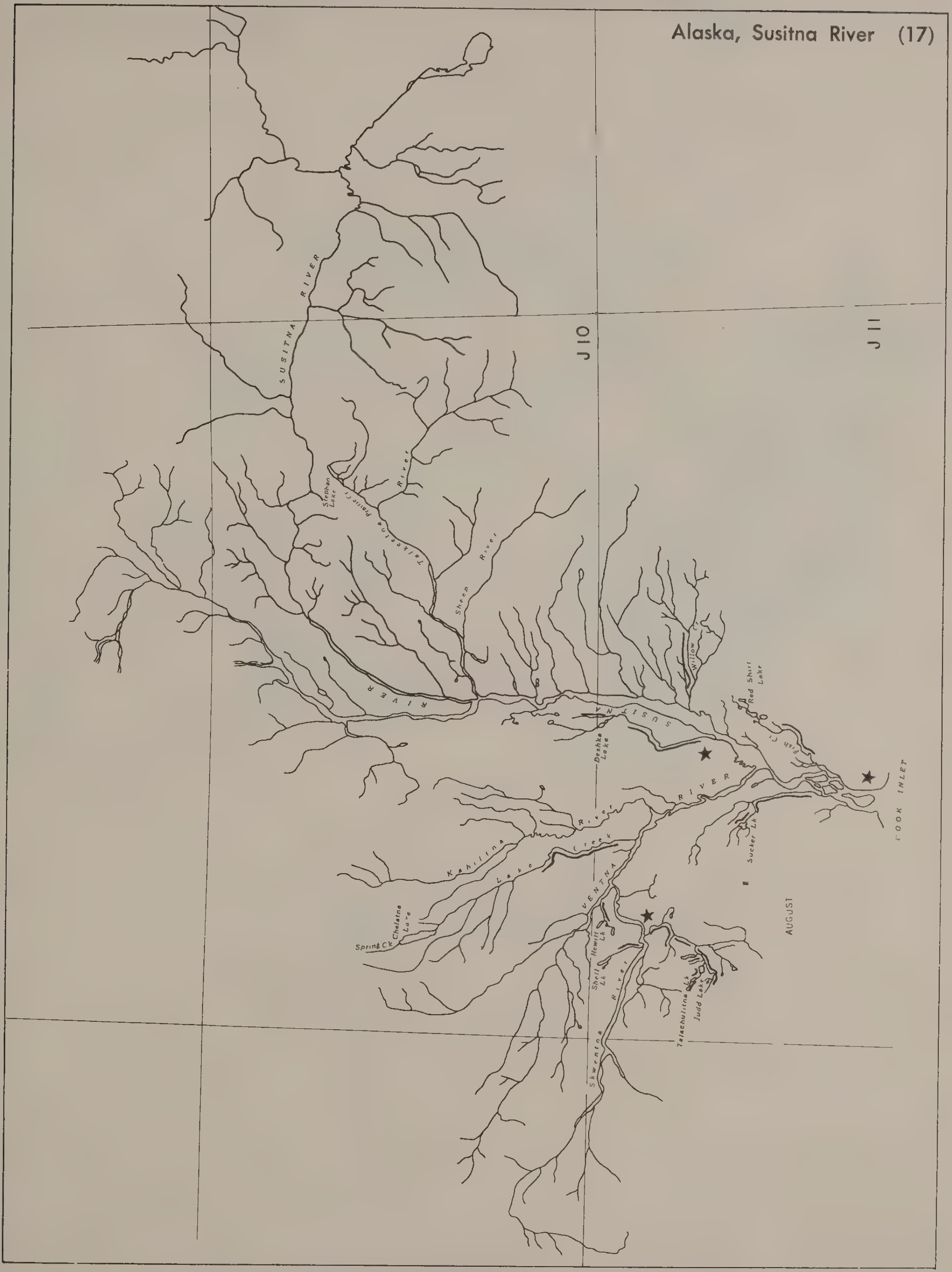
Alaska, Susitna River (17)
J10
J11
SUSITNA RIVER
Stephan Lake
Prairie Cr.
Talkeetna River
Sheep River
RIVER
Willow Cr.
Red Shirt Lake
SUSITNA
Deshka Lake
RIVER
Fish Cr.
COOK INLET
Sucker Lk
AUGUST
Kahiltna River
Lake Creek
YENTNA
Chelatna Lake
Spring Ck
Hewitt Lk
Shell Lk
River
Talachulitna Ck
Judd Lake
Skwentna

FIGURE 78. Spawning grounds of pink salmon in Central Alaska (Susitna River).

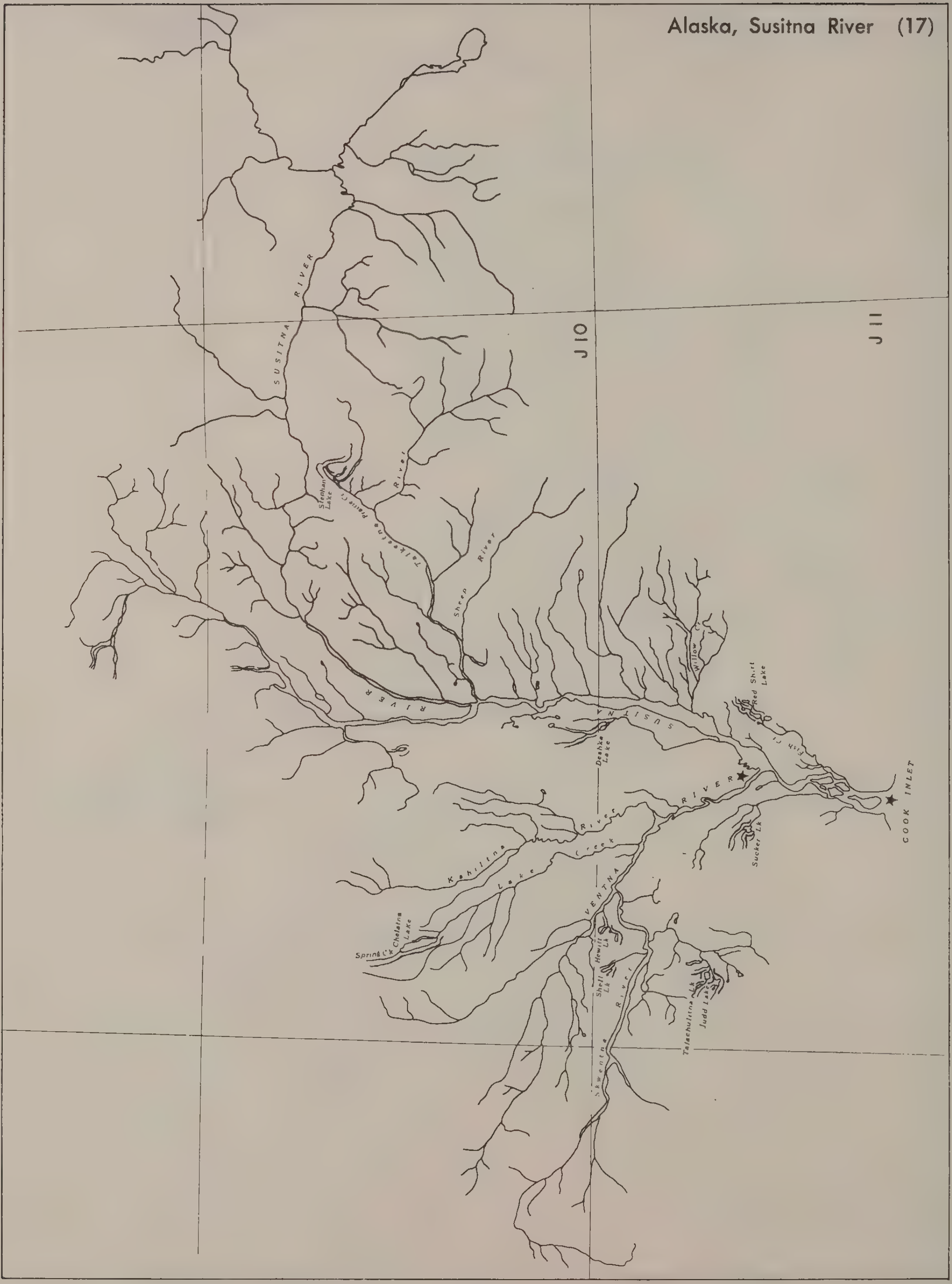
Alaska, Susitna River (17)
J 10
J 11
SUSITNA RIVER
Stephan Lake
Prairie Cr.
Talkeetna River
Sheep River
RIVER
SUSITNA
Willow Cr.
Red Shirt Lake
Fish Cr.
Deshka Lake
RIVER
COOK INLET
Sucker Lk
River
Creek
Kahiltna
Lake
YENTNA
Chelatna Lake
Spring Ck
Hewitt Lk
Shell Lk
River
Talachulitna Lk
Judd Lake
Skwentna

FIGURE 79. Spawning grounds of sockeye salmon in Central Alaska (Susitna River).

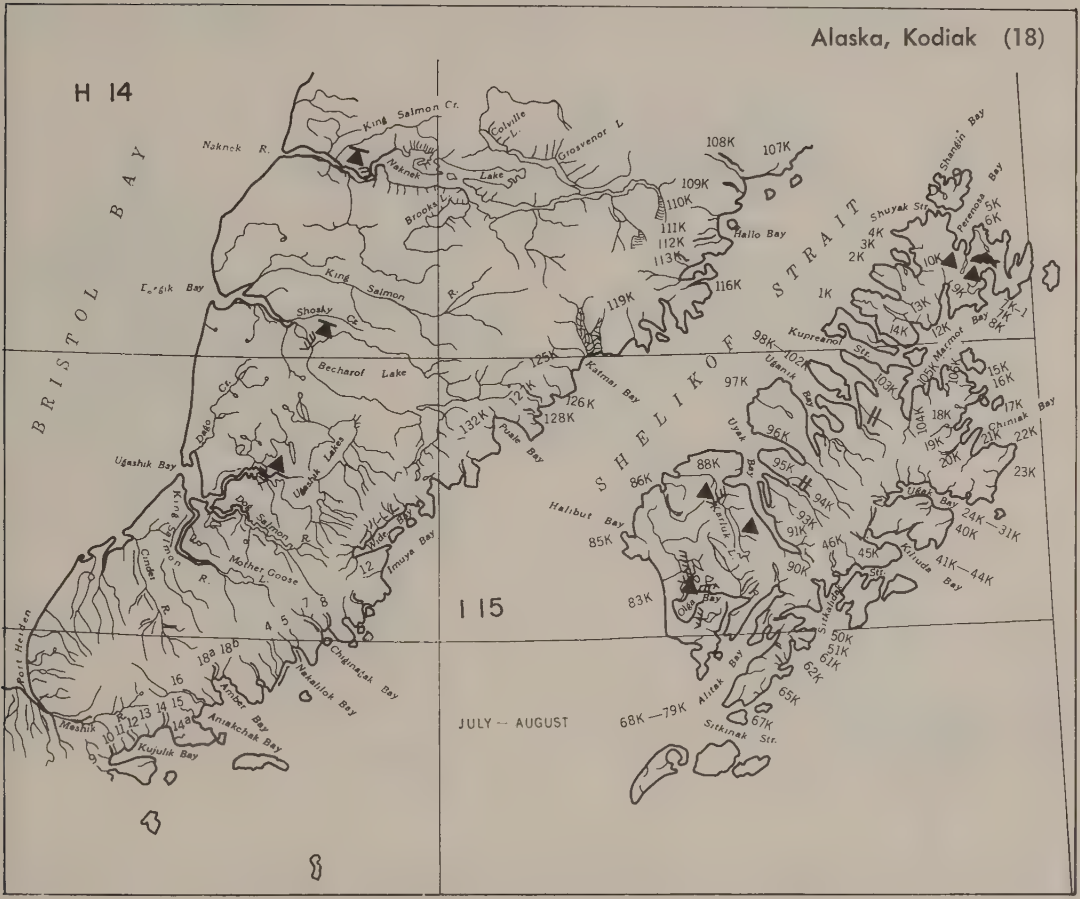
Alaska, Kodiak (18)
H 14
I 15
BRISTOL BAY
SHELIKOF STRAIT
Naknek R.
King Salmon Cr.
Naknek
Lake
Brooks L.
Colville L.
Grosvenor L.
King Salmon R.
Shosky Cr.
Becharof Lake
Egegik Bay
Dago Cr.
Ugashik Bay
Ugashik Lakes
King Salmon R.
Dog Salmon R.
Mother Goose L.
Cinder R.
Port Heiden
Meshik R.
Kujulik Bay
Aniakchak Bay
Amber Bay
Nakalilok Bay
Chiginagak Bay
Wide Bay
Imuya Bay
Puale Bay
Katmai Bay
Hallo Bay
Shuyak Str.
Shangin Bay
Perenosa Bay
Marmot Bay
Kupreanof Str.
Uganik Bay
Uyak Bay
Karluk L.
Halibut Bay
Olga Bay
Ugak Bay
Chiniak Bay
Kiliuda Bay
Sitkalidak Str.
Alitak Bay
Sitkinak Str.
JULY — AUGUST
1K
2K
3K
4K
5K
6K
7K
7K-1
8K
9K
10K
12K
13K
14K
15K
16K
17K
18K
19K
20K
21K
22K
23K
24K—31K
40K
41K—44K
45K
46K
50K
51K
61K
62K
65K
67K
68K—79K
83K
85K
86K
88K
90K
91K
93K
94K
95K
96K
97K
98K
102K
103K
104K
105K
107K
108K
109K
110K
111K
112K
113K
116K
119K
121K
125K
126K
128K
132K
4
5
7
8
9
10
11
12
13
14
14a
15
16
18a
18b

Figure 80. Spawning grounds of chum salmon in Central Alaska (Kodiak).

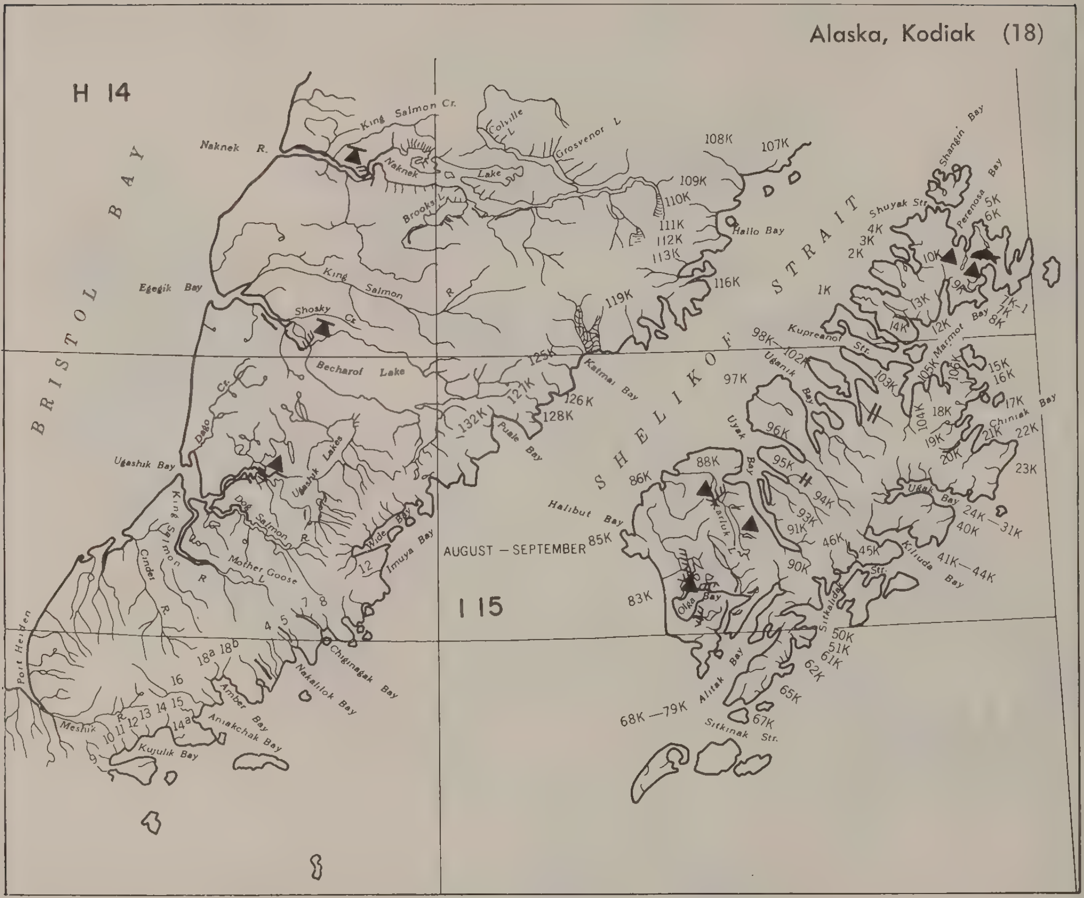
Alaska, Kodiak (18)
H 14
I 15
AUGUST — SEPTEMBER
BRISTOL BAY
SHELIKOF STRAIT
Naknek R.
King Salmon Cr.
Naknek
Lake
Colville L
Grosvenor L
Brooks L
Egegik Bay
King Salmon R
Shosky Cr.
Becharof Lake
Dago Cr.
Ugashik Bay
Ugashik Lakes
Dog Salmon R.
King Salmon R
Cinder R.
Mother Goose L
Wide Bay
Imuya Bay
Puale Bay
Katmai Bay
Hallo Bay
Port Heiden
Meshik R
Kujulik Bay
Aniakchak Bay
Amber Bay
Nakalilok Bay
Chiginagak Bay
Halibut Bay
Uyak Bay
Uganik Bay
Karluk L
Olga Bay
Alitak Bay
Sitkinak Str.
Sitkalidak Str.
Kiliuda Bay
Ugak Bay
Chiniak Bay
Marmot Bay
Perenosa Bay
Shangin Bay
Shuyak Str.
Kupreanof Str.
4 5 7 8
9 10 11 12 13 14 14a 15 16 18a 18b
12
107K 108K 109K 110K 111K 112K 113K 116K 119K
125K 127K 126K 128K 132K
1K 2K 3K 4K 5K 6K 7K 7K-1 8K 9K 10K 12K 13K 14K
15K 16K 17K 18K 19K 20K 21K 22K 23K 24K—31K 40K 41K—44K 45K 46K
50K 51K 61K 62K 65K 67K 68K—79K
83K 85K 86K 88K 90K 91K 93K 94K 95K 96K 97K
98K—102K 103K 104K 105K 106K

FIGURE 81. Spawning grounds of coho salmon in Central Alaska (Kodiak).

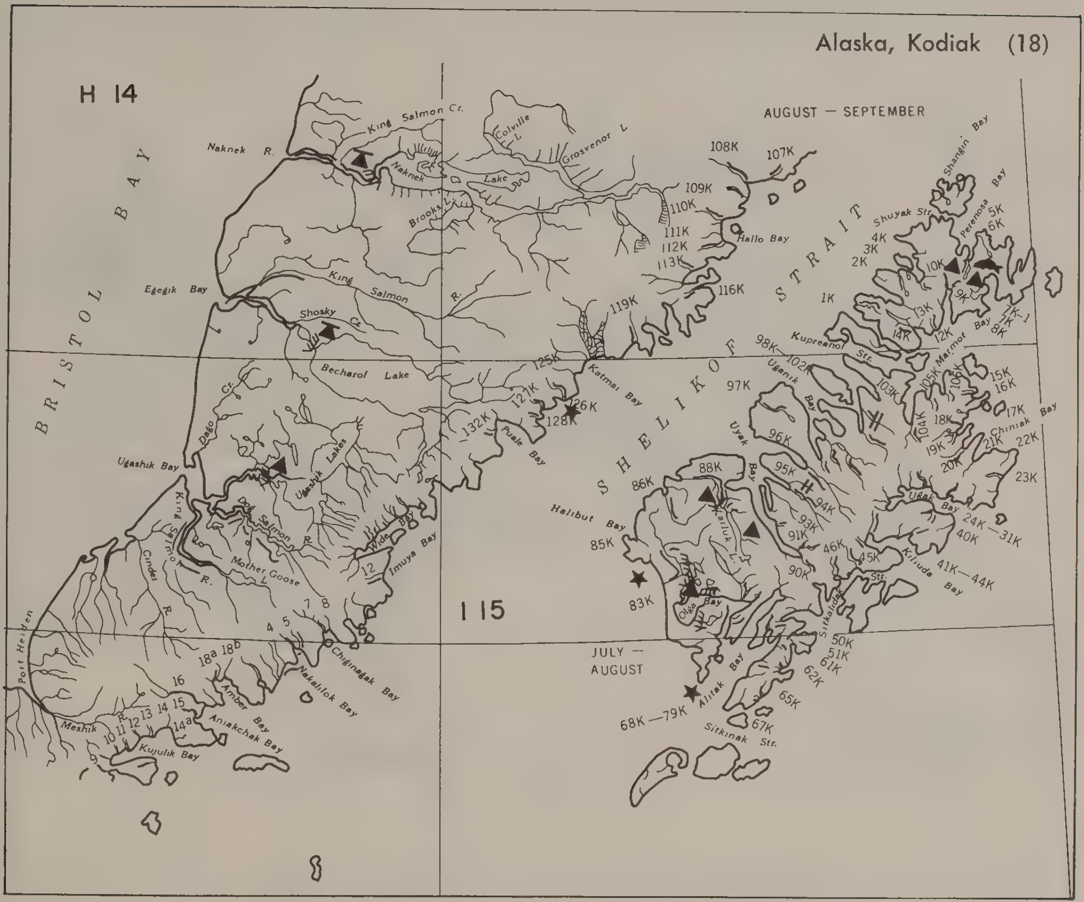
Alaska, Kodiak (18)
H 14
I 15
AUGUST — SEPTEMBER
JULY — AUGUST
BRISTOL BAY
SHELIKOF STRAIT
Naknek R.
King Salmon Cr.
Naknek
Colville L.
Grosvenor L.
Lake
Brooks L.
Egegik Bay
King Salmon R.
Shosky Cr.
Becharof Lake
Dago Cr.
Ugashik Bay
Ugashik Lakes
King Salmon R.
Dog Salmon R.
Cinder R.
Mother Goose L.
Wide Bay
Imuya Bay
Port Heiden
Meshik R.
Kujulik Bay
Aniakchak Bay
Amber Bay
Nakalilok Bay
Chiginagak Bay
Puale Bay
Katmai Bay
Hallo Bay
Shuyak Str.
Shangin Bay
Perenosa Bay
Kupreanof Str.
Uganik Bay
Uyak Bay
Marmot Bay
Chiniak Bay
Halibut Bay
Karluk L.
Olga Bay
Ugak Bay
Kiliuda Bay
Sitkalidak Str.
Alitak Bay
Sitkinak Str.
108K
107K
109K
110K
111K
112K
113K
116K
119K
125K
121K
126K
128K
132K
1K
2K
3K
4K
5K
6K
7K
8K
9K
10K
12K
13K
14K
15K
16K
17K
18K
19K
20K
21K
22K
23K
24K — 31K
40K
41K — 44K
45K
46K
50K
51K
61K
62K
65K
67K
68K — 79K
83K
85K
86K
88K
90K
91K
93K
94K
95K
96K
97K
98K — 102K
103K
104K
105K
106K
LK-1
4 5
7 8
9
10 11 12 13 14 15
14a
16
18a 18b
12

Figure 82. Spawning grounds of pink salmon in Central Alaska (Kodiak).

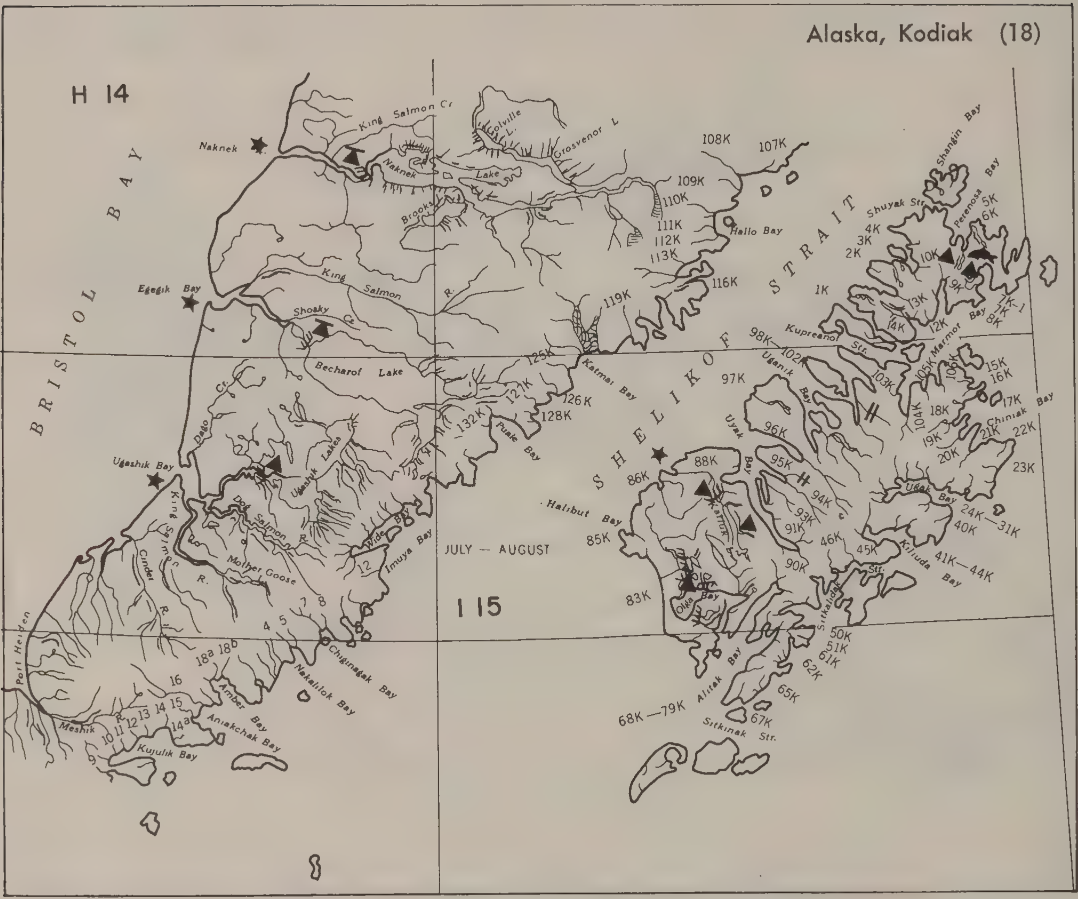
Alaska, Kodiak (18)
H 14
I 15
JULY — AUGUST
BRISTOL BAY
SHELIKOF STRAIT
Naknek
King Salmon Cr
Naknek
Lake
Colville L.
Grosvenor L
Brooks
Egegik Bay
King Salmon R.
Shosky Cr.
Becharof Lake
Dago Cr.
Ugashik Bay
Ugashik Lakes
King Salmon R.
Dog Salmon R.
Cinder R.
Mother Goose L.
Port Heiden
Meshik R.
Kujulik Bay
Aniakchak Bay
Amber Bay
Nakalilok Bay
Chiginagak Bay
Wide Bay
Imuya Bay
Puale Bay
Katmai Bay
Hallo Bay
Halibut Bay
Uyak Bay
Karluk
Olga Bay
Alitak Bay
Sitkinak Str.
Sitkalidak Str.
Kiliuda Bay
Ugak Bay
Chiniak Bay
Marmot Bay
Uganik Bay
Kupreanof Str.
Shuyak Str.
Shangin Bay
Perenosa Bay
1K
2K
3K
4K
5K
6K
7K-1
7K
8K
9K
10K
12K
13K
14K
15K
16K
17K
18K
19K
20K
21K
22K
23K
24K—31K
40K
41K—44K
45K
46K
50K
51K
61K
62K
65K
67K
68K —79K
83K
85K
86K
88K
90K
91K
93K
94K
95K
96K
97K
98K—102K
103K
104K
105K
106K
107K
108K
109K
110K
111K
112K
113K
116K
119K
125K
126K
127K
128K
132K
4
5
7
8
9
10
11
12
12
13
14
14a
15
16
18a
18b

FIGURE 83. Spawning grounds of sockeye salmon in Central Alaska (Kodiak).

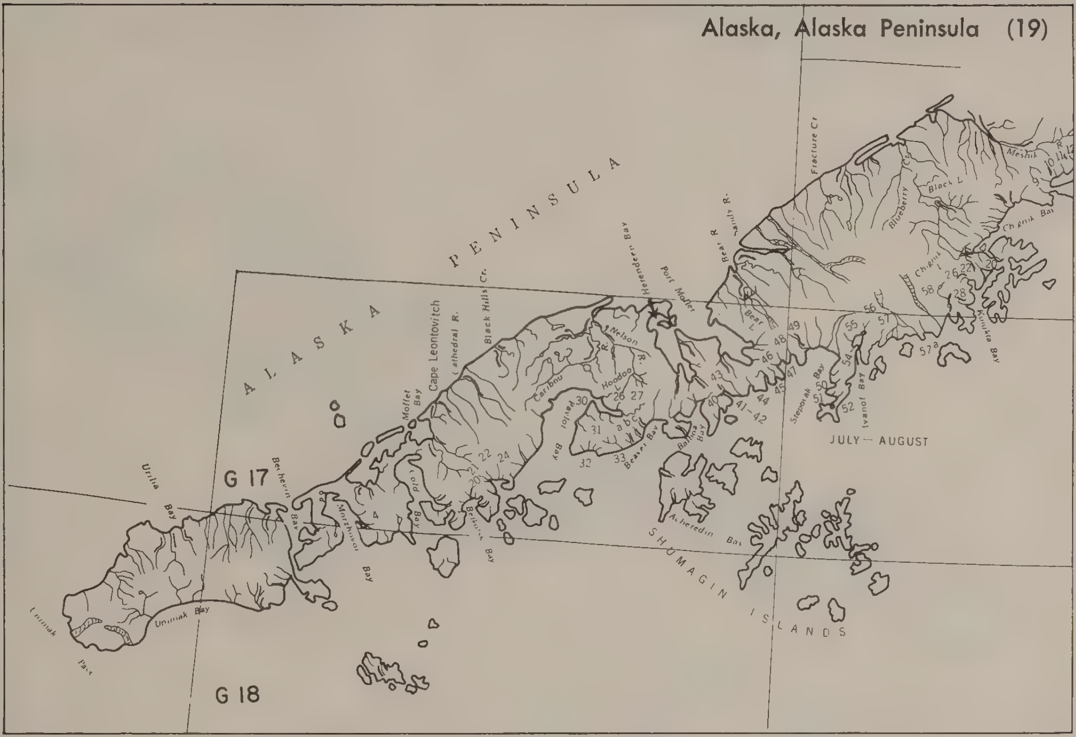
Alaska, Alaska Peninsula (19)
ALASKA PENINSULA
G 17
G 18
Urilia Bay
Bechevin Bay
Morzhovoi Bay
Cold Bay
Belkofski Bay
Unimak Bay
Unimak Pass
Moffet Bay
Cape Leontovitch
Cathedral R.
Black Hills Cr.
Caribou
Pavlof Bay
Nelson R.
Hoodoo L
Herendeen Bay
Port Moller
Bear R
Sandy R.
Bear L
Fracture Cr
Blueberry Cr.
Black L
Meshik R
Chignik Bay
Chignik L
Kujulik Bay
Stepovak Bay
Ivanof Bay
Beaver Bay
Balboa Bay
Acheredin Bay
SHUMAGIN ISLANDS
JULY — AUGUST
4
20
21
22
24
26
27
30
31
32
33
a b c
40
41–42
43
44
45
46
47
48
49
50
51
52
54
55
56
57
57a
58
26
22
20
28
9
10
11
12

Figure 84. Spawning grounds of chum salmon in Western Alaska (Peninsula).

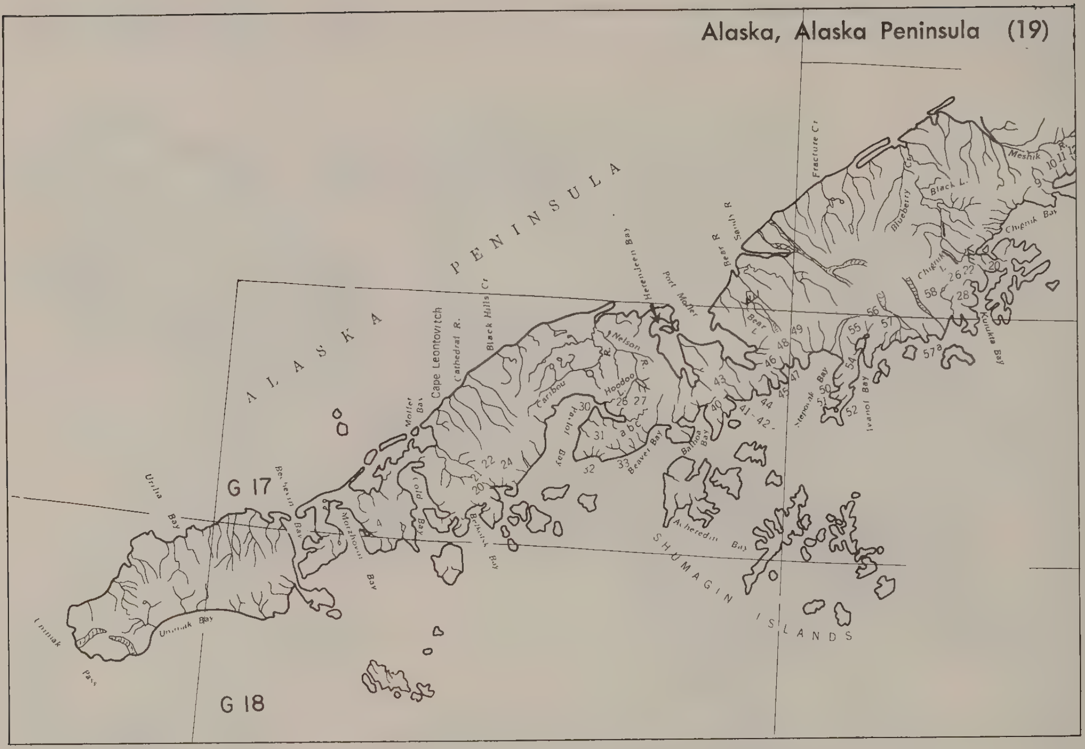
Alaska, Alaska Peninsula (19)
ALASKA PENINSULA
G 17
G 18
Unimak Pass
Urilia Bay
Unimak Bay
Bechevin Bay
Morzhovoi Bay
Moller Bay
Cape Leontovitch
Cathedral R.
Black Hills Cr
Cold Bay
Belkofski Bay
Caribou
Pavlof Bay
Beaver Bay
Balboa Bay
Nelson R.
Hoodoo L.
Herendeen Bay
Port Moller
Bear R
Sandy R
Bear L
Fracture Cr
Blueberry Cr
Black L.
Meshik R.
Chignik Bay
Chignik L.
Kuiukta Bay
Stepovak Bay
Ivanof Bay
Unga Bay
Acheredin Bay
SHUMAGIN ISLANDS
4
20
21
22
24
26
27
30
31
32
33
a
b
c
40
41
42
43
44
45
46
47
48
49
50
51
52
54
55
56
57
57a
58
9
10
11
12
20
22
26
28

FIGURE 85. Spawning grounds of coho salmon in Western Alaska (Peninsula).

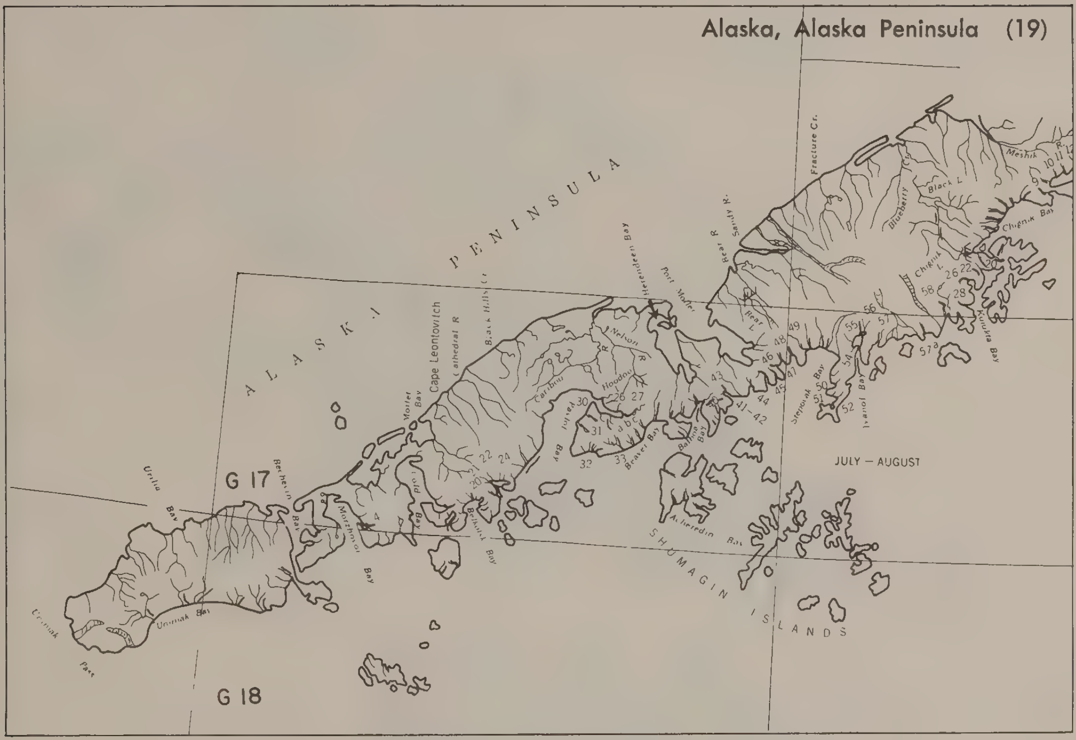
Alaska, Alaska Peninsula (19)
ALASKA PENINSULA
G 17
G 18
Unimak Pass
Unimak Bay
Urilia Bay
Bechevin Bay
Morzhovoi Bay
Cold Bay
Belkofski Bay
Moffet Bay
Cape Leontovitch
Cathedral R
Black Hills Cr
Caribou
Pavlof Bay
Nelson R
Hoodoo L
Herendeen Bay
Port Moller
Bear R
Sandy R.
Bear L
Fracture Cr.
Blueberry Cr
Black L
Meshik R.
Chignik Bay
Chignik L
Kujulik Bay
Beaver Bay
Balboa Bay
Stepovak Bay
Ivanof Bay
Canoe Bay
Unga
JULY — AUGUST
SHUMAGIN ISLANDS
4
20
21
22
24
26
27
30
31
32
33
a b c
41-42
43
44
45
46
47
48
49
50
51
52
54
55
56
57
57a
58
26
22
28
9
10
11
12

Figure 86. Spawning grounds of pink salmon in Western Alaska (Peninsula).

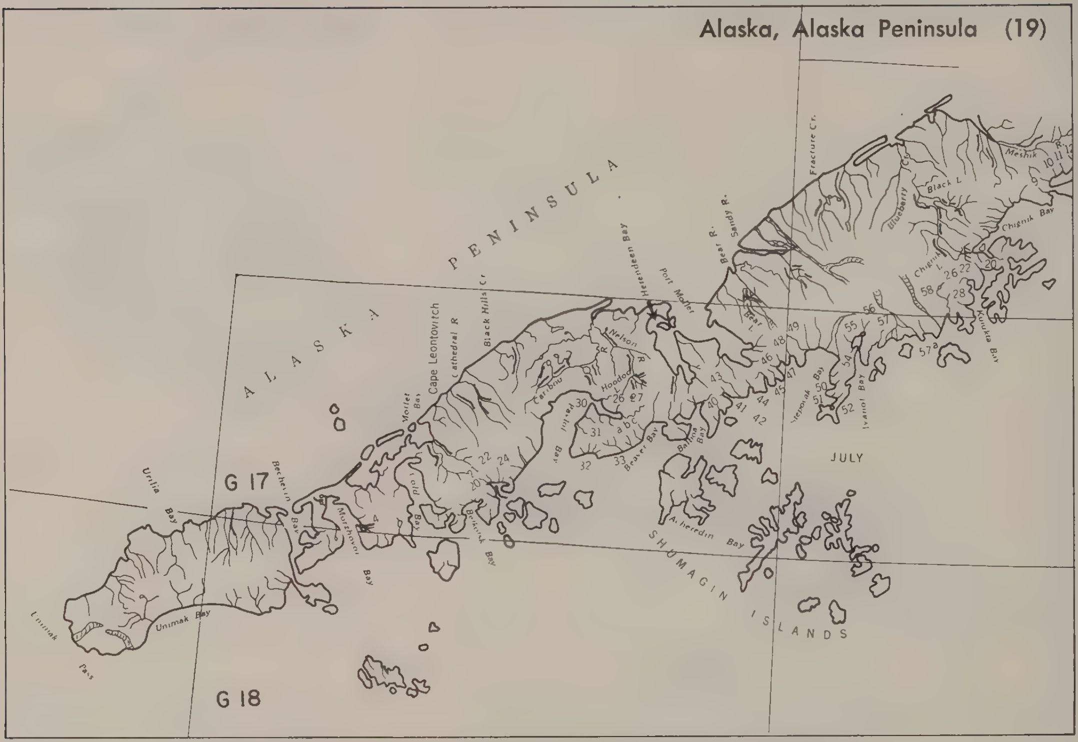
Alaska, Alaska Peninsula (19)
ALASKA PENINSULA
G 17
G 18
JULY
SHUMAGIN ISLANDS
Unimak Pass
Unimak Bay
Urilia Bay
Becherin Bay
Morzhovoi Bay
Cold Bay
Belkofsk Bay
Moffet Bay
Cape Leontovitch
Cathedral R
Black Hills Cr
Caribou
Nelson R
Hoodoo L
Pavlof Bay
Beaver Bay
Balboa Bay
Herendeen Bay
Port Moller
Bear R.
Sandy R.
Bear L
Fracture Cr.
Blueberry Cr.
Black L
Meshik R.
Chignik Bay
Chignik L
Kujulik Bay
Stepovak Bay
Ivanof Bay
Unga Strait
Acheredin Bay
4
9
10
11
12
20
22
24
26
27
28
30
31
32
33
a
b
c
40
41
42
43
44
45
46
47
48
49
50
51
52
54
55
56
57
57a
58

FIGURE 87. Spawning grounds of sockeye salmon in Western Alaska (Peninsula).

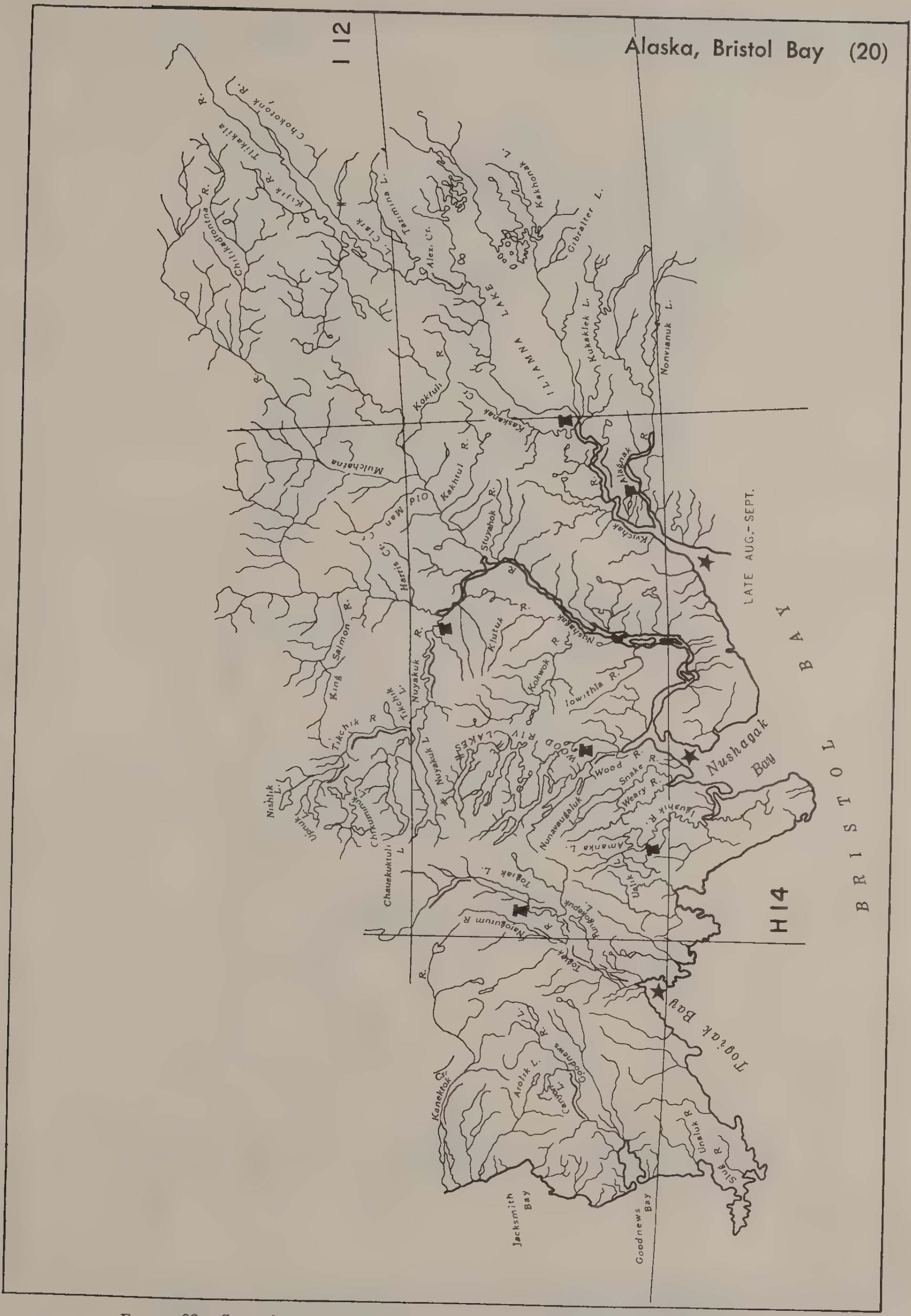
Alaska, Bristol Bay (20)
I 12
H14
BRISTOL BAY
LATE AUG.-SEPT.
Nushagak Bay
Togiak Bay
Goodnews Bay
Jacksmith Bay
ILIAMNA LAKE
Kakhonak L.
Gibraltar L.
Kukaklek L.
Nonvianuk L.
Tazimina L.
Clark L.
Alex. Cr.
Chokotonk R.
Tlikakila R.
Kijik R.
Chilikadrotna R.
Koktuli R.
Kaskanak Cr.
Alagnak R.
Kvichak
Mulchatna
Old Man Cr.
Kakhtul R.
Stuyahok R.
Harris Cr.
Nushagak R.
Klutuk R.
Kokwok R.
Iowithla R.
King Salmon R.
Nuyakuk R.
Tikchik L.
Tikchik R.
Nishlik L.
Upnuk L.
Chikuminuk L.
Chauekuktuli L.
Nuyakuk L.
WOOD RIV. LAKES
Wood R.
Snake R.
Weary R.
Igushik R.
Nunavaugaluk L.
Amanka L.
Ualik L.
Togiak L.
Togiak R.
Kanektok R.
Arolik L.
Goodnews R.
Unaluk R.

Figure 88. Spawning grounds of chinook salmon in Western Alaska (Bristol Bay).

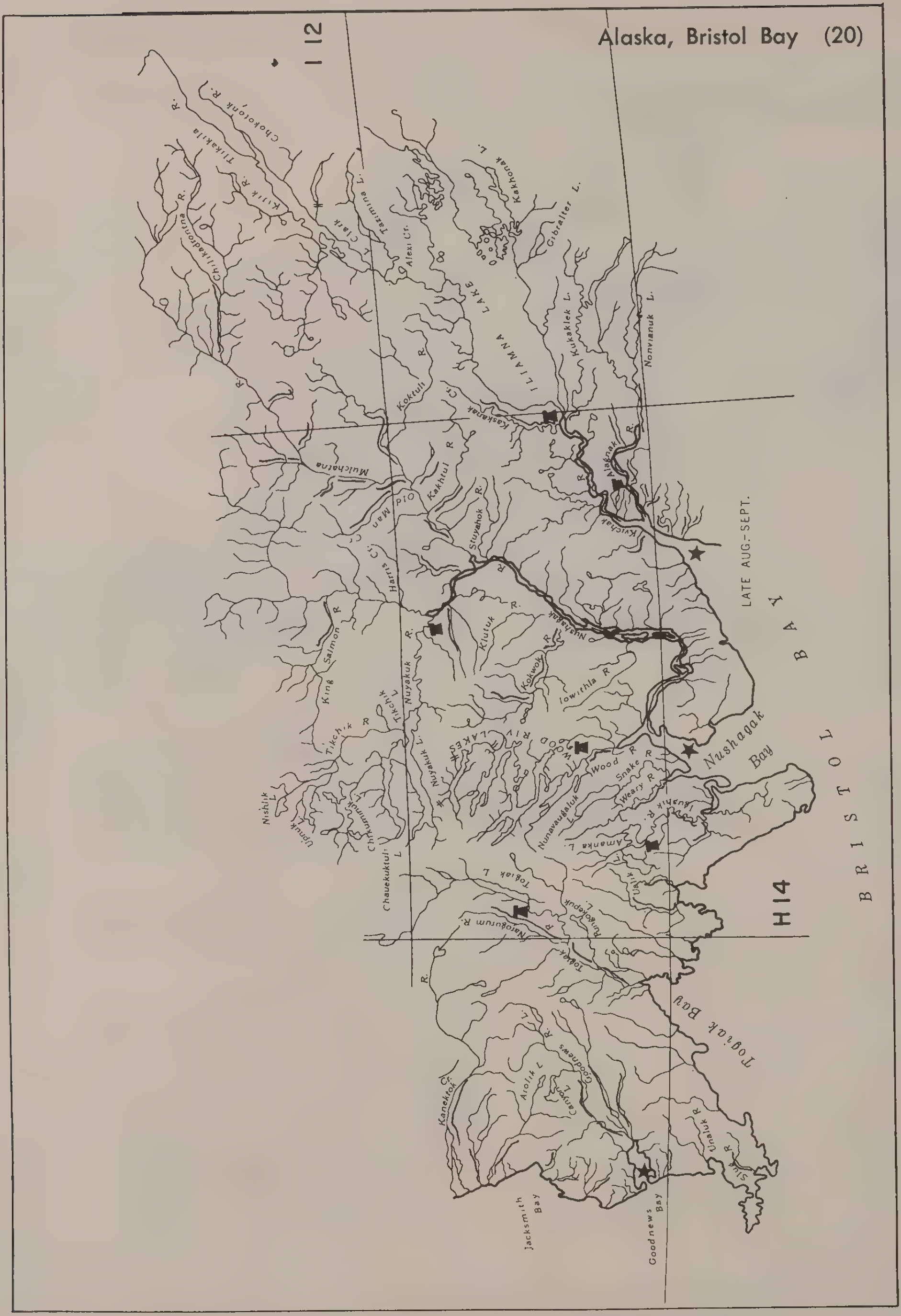
Alaska, Bristol Bay (20)
I 12
H14
LATE AUG.-SEPT.
BRISTOL BAY
Nushagak Bay
Togiak Bay
Chokotonk R.
Tlikakila R.
Kijik R.
Chilikadrotna R.
Clark
Tazimina L.
Alexi Cr.
Kakhonak L.
Gibraltar L.
ILIAMNA LAKE
Kukaklek L.
Nonvianuk L.
Koktuli R.
Kaskanak Cr.
Alagnak R.
Kvichak
Mulchatna
Old Man Cr.
Kakhtul R.
Stuyahok R.
Harris Cr.
Nushagak R.
Klutuk R.
Kokwok R.
Iowithla R.
King Salmon R.
Nuyakuk R.
Tikchik L.
Tikchik R.
Nuyakuk L.
WOOD RIV. LAKES
Wood R.
Snake R.
Weary R.
Igushik R.
Nunavaugaluk L.
Amanka L.
Nishlik L.
Upnuk L.
Chikuminuk L.
Chauekuktuli L.
Togiak L.
Kulukak
Nanogurum R.
Togiak R.
Ungalikthluk
Kanektok Cr.
Arolik L.
Goodnews R.
Canyon L.
Unaluk R.
Slug R.
Jacksmith Bay
Goodnews Bay

Figure 89. Spawning grounds of chum salmon in Western Alaska (Bristol Bay).

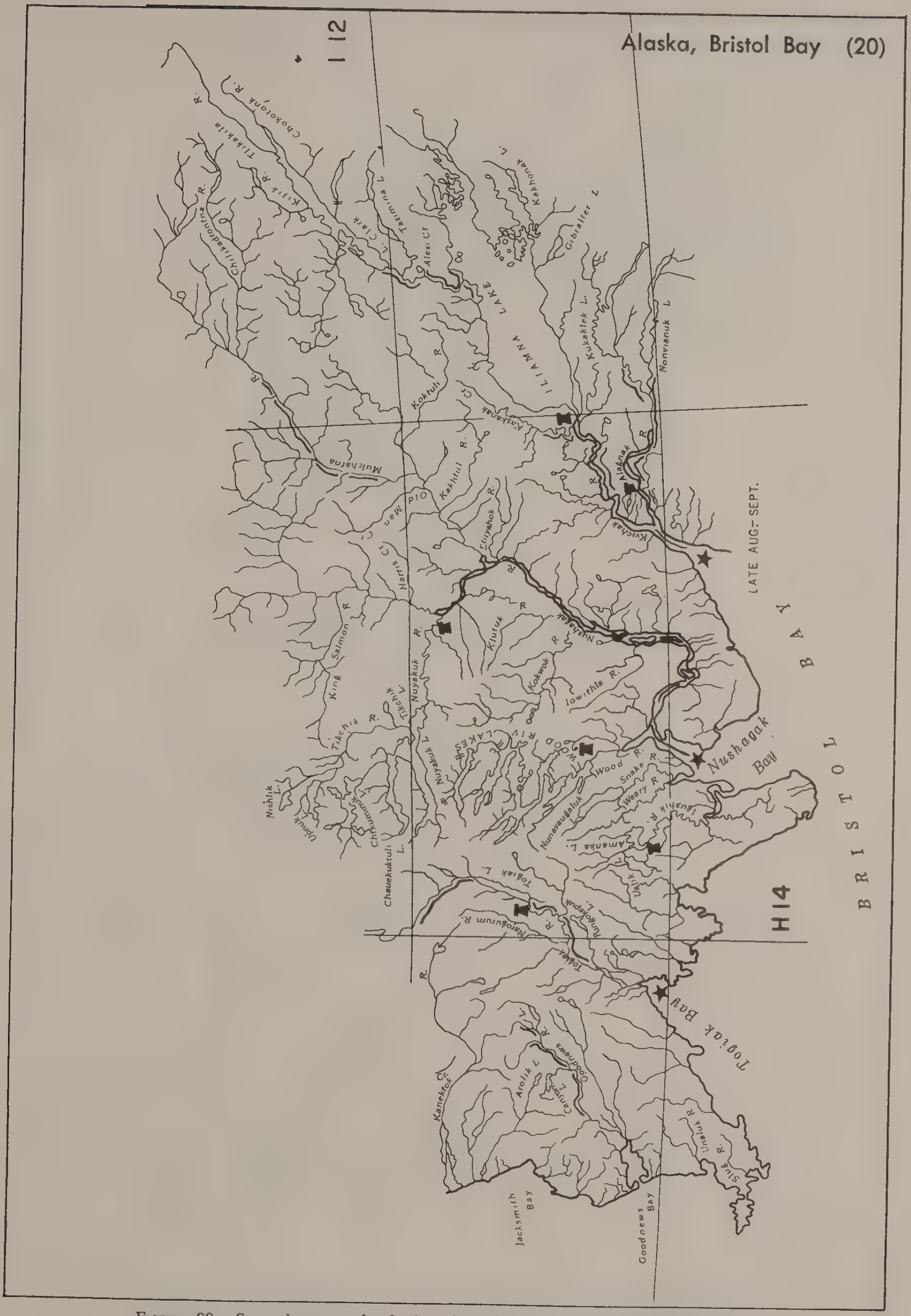
Alaska, Bristol Bay (20)
I 12
H14
LATE AUG.-SEPT.
BRISTOL BAY
Nushagak Bay
Togiak Bay
Goodnews Bay
Jacksmith Bay
ILIAMNA LAKE
Chokotonk R.
Tlikakila R.
Kijik R.
Chilikadrotna R.
Mulchatna R.
Koktuli R.
Kaskanak Cr.
Kakhonak L.
Gibraltar L.
Tazimina L.
Clark L.
Alexi Cr.
Kukaklek L.
Nonvianuk L.
Alagnak R.
Kvichak R.
Kahtiul R.
Old Man Cr.
Harris Cr.
Stuyahok R.
Nushagak R.
Klutuk R.
Kokwok R.
Iowithla R.
King Salmon R.
Tikchik R.
Tikchik L.
Nuyakuk R.
Nuyakuk L.
Nishlik L.
Upnuk L.
Chikuminuk L.
Chauekuktuli L.
WOOD RIV. LAKES
Wood R.
Snake R.
Weary R.
Nunavaugaluk L.
Amanka L.
Igushik R.
Ualik L.
Togiak L.
Togiak R.
Pungokepuk L.
Kanektok R.
Arolik L.
Canyon L.
Goodnews R.
Unaluk R.
Slug R.

FIGURE 90. Spawning grounds of coho salmon in Western Alaska (Bristol Bay).

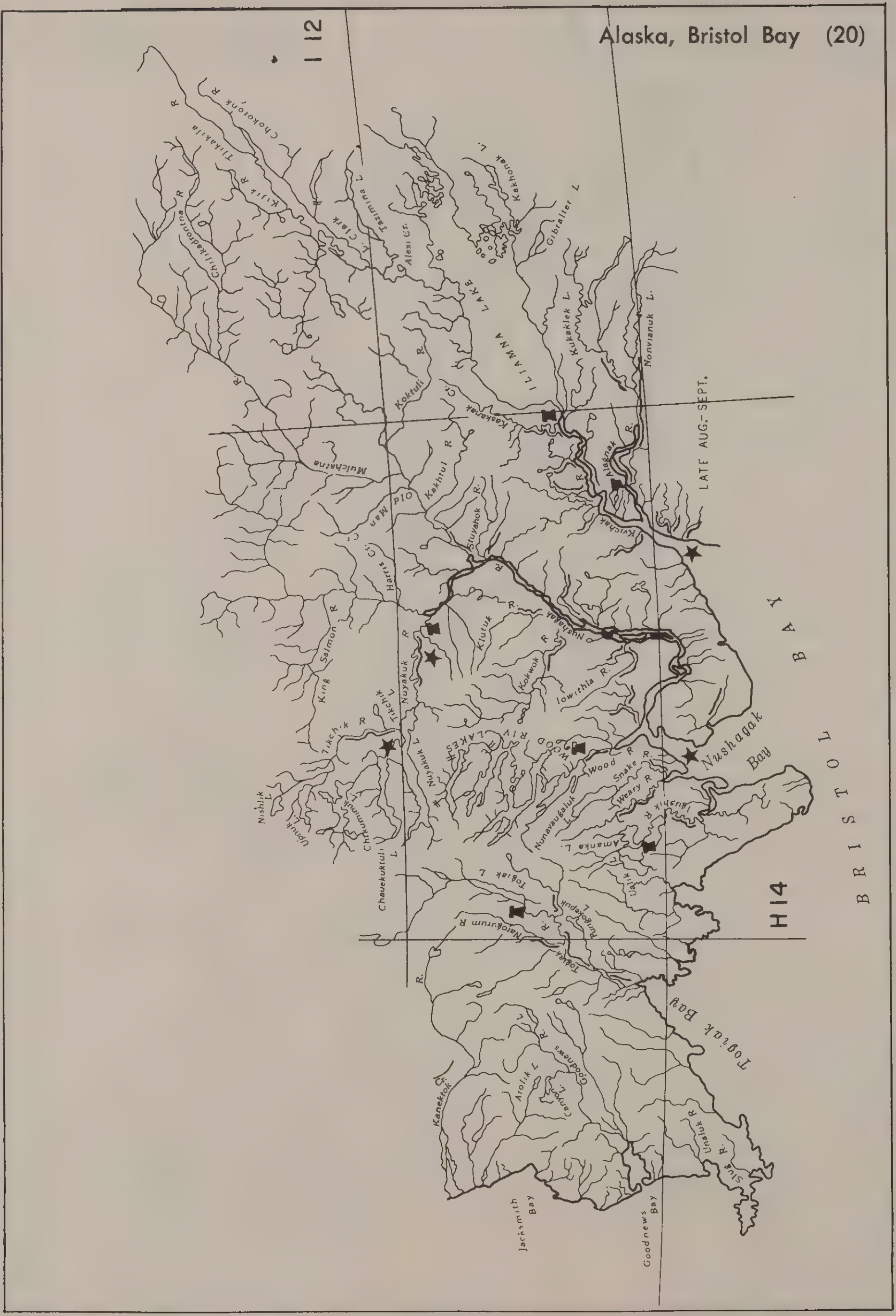
Alaska, Bristol Bay (20)
112
H14
LATE AUG.-SEPT.
BRISTOL BAY
Nushagak Bay
Togiak Bay
ILIAMNA LAKE
WOOD RIV. LAKES
Chokotonk R.
Tlikakila R.
Kijik R.
Chilikadrotna R.
Clark L.
Tazimina L.
Alexi Cr.
Kakhonak L.
Gibraltar L.
Kukaklek L.
Nonvianuk L.
Koktuli R.
Kaskanak Cr.
Alagnak R.
Kvichak R.
Mulchatna
Old Man Cr.
Kakhtul R.
Stuyahok R.
Harris Cr.
Salmon R.
King Salmon
Klutuk
Nushagak R.
Kokwok R.
Iowithla R.
Nuyakuk R.
Nuyakuk L.
Tikchik L.
Tikchik R.
Wood R.
Snake R.
Weary R.
Igushik R.
Nunavaugaluk L.
Amanka L.
Nishlik L.
Upnuk L.
Chikuminuk L.
Chauekuktuli L.
Ualik
Togiak L.
Kulukak R.
Nanagurum R.
Togiak R.
Kanektok Cr.
Arolik L.
Goodnews R.
Canyon L.
Unaluk R.
Slug R.
Jacksmith Bay
Goodnews Bay

Figure 91. Spawning grounds of pink salmon in Western Alaska (Bristol Bay).

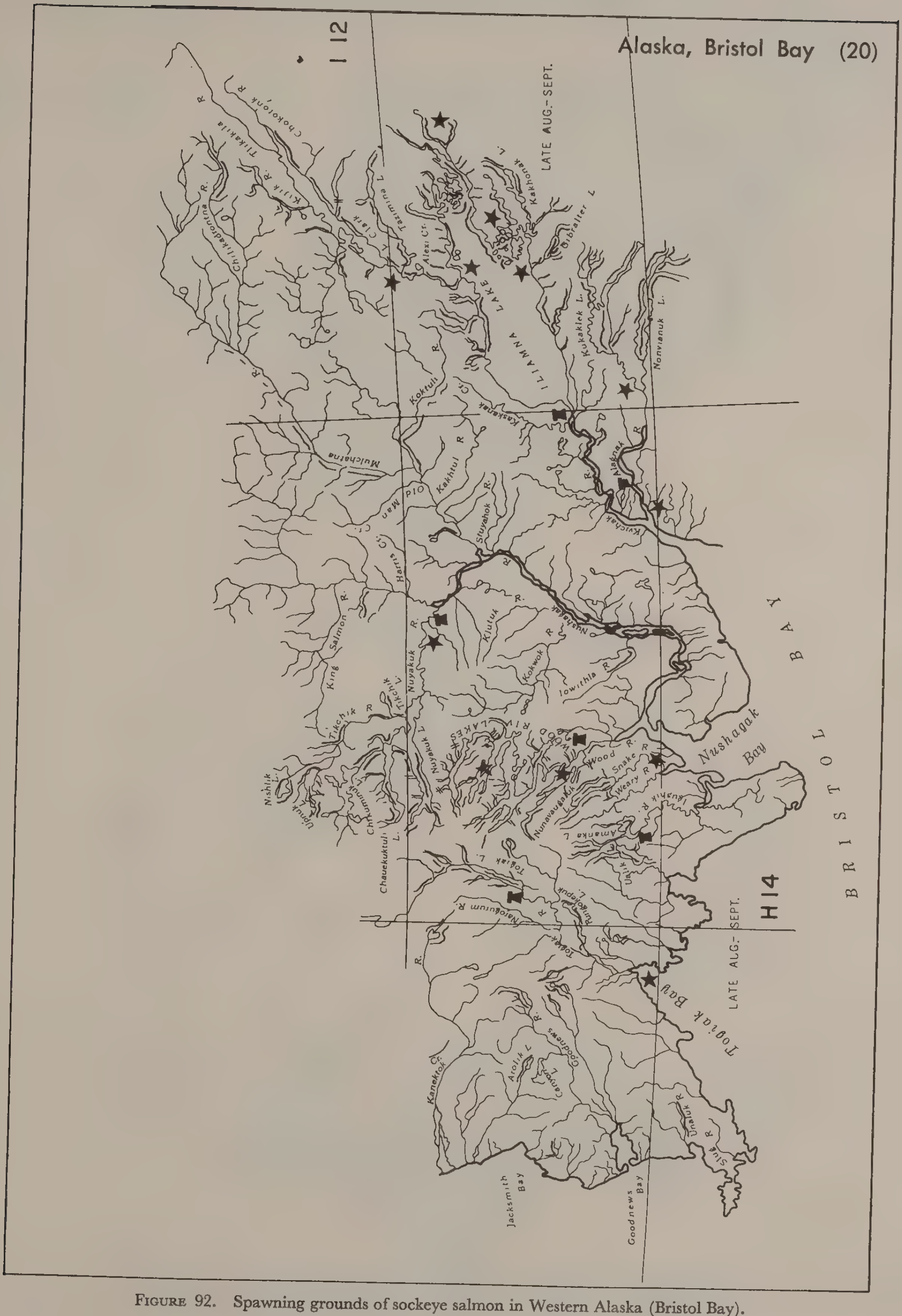
Alaska, Bristol Bay (20)
I 12
H14
LATE AUG.–SEPT.
LATE AUG.–SEPT.
ILIAMNA LAKE
BRISTOL BAY
Nushagak Bay
Togiak Bay
Jacksmith Bay
Goodnews Bay
Chokotonk R.
Tlikakila R.
Kijik R.
Chilikadrotna R.
Clark L.
Tazimina L.
Alexi Cr.
Kakhonak L.
Gibraltar L.
Kukaklek L.
Nonvianuk L.
Koktuli R.
Kaskanak Cr.
Alagnak R.
Kvichak
Mulchatna R.
Old Man Cr.
Kakhtul R.
Stuyahok R.
Harris Cr.
Nushagak R.
King Salmon R.
Nuyakuk R.
Klutuk R.
Kokwok R.
Iowithla R.
Tikchik L.
Tikchik R.
Nishlik L.
Upnuk L.
Chikuminuk L.
Chauekuktuli L.
Nuyakuk L.
WOOD RIVER LAKES
Wood R.
Snake R.
Weary R.
Nunavaugaluk L.
Amanka L.
Igushik R.
Ualik L.
Togiak L.
Togiak R.
Kanektok Cr.
Arolik L.
Goodnews R.
Unaluk R.
Slug R.

Figure 92. Spawning grounds of sockeye salmon in Western Alaska (Bristol Bay).

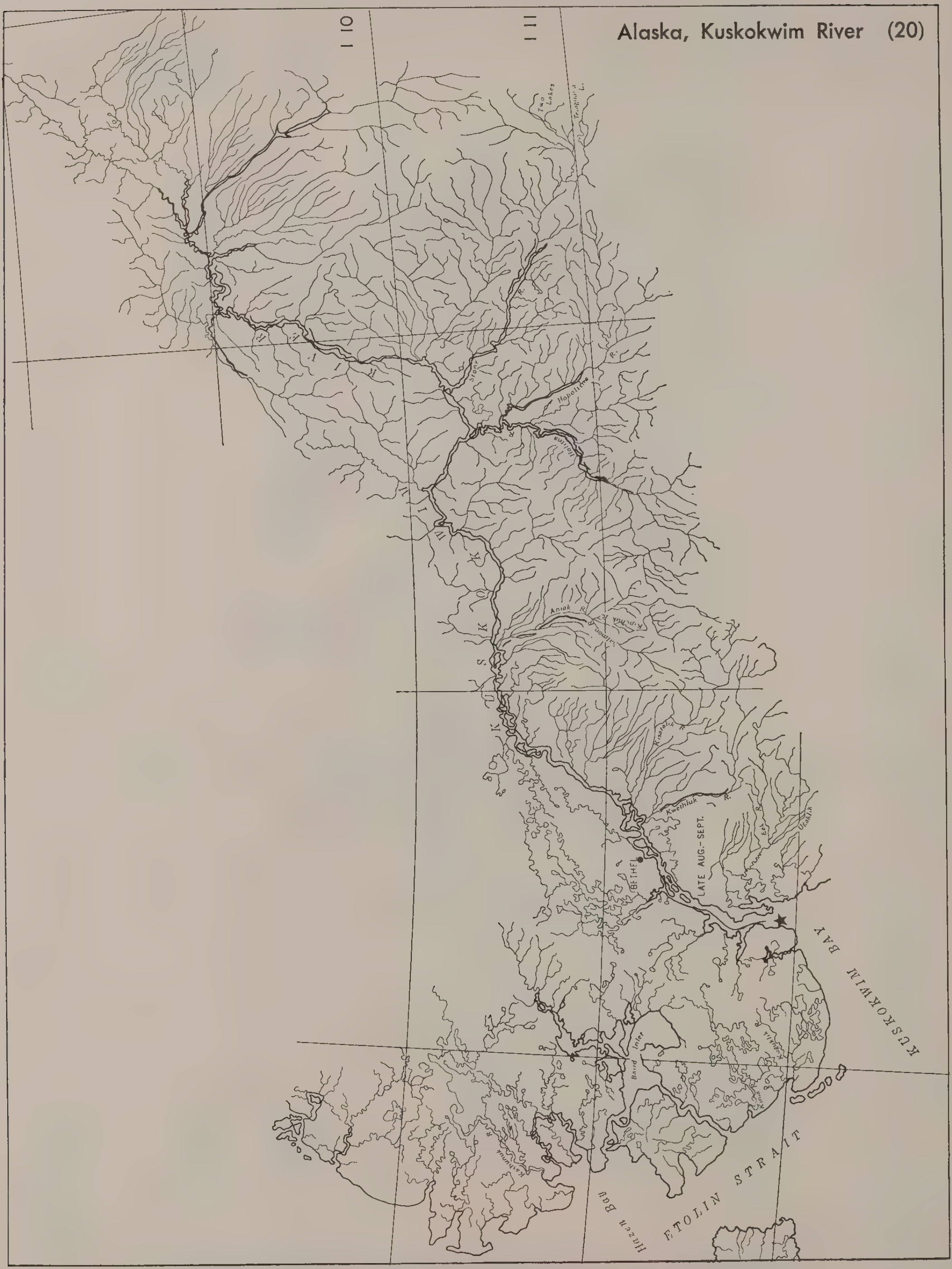
Alaska, Kuskokwim River (20)
Two Lakes
Telaquana L.
KUSKOKWIM RIVER
Stony R.
Hoholitna R.
Holitna R.
Aniak R.
Kipchuk R.
Salmon R.
Kisaralik R.
Kwethluk R.
Eek R.
BETHEL
LATE AUG.-SEPT.
KUSKOKWIM BAY
Baird Inlet
Hazen Bay
ETOLIN STRAIT

FIGURE 93. Spawning grounds of chinook salmon in Western Alaska (Kuskokwim River).

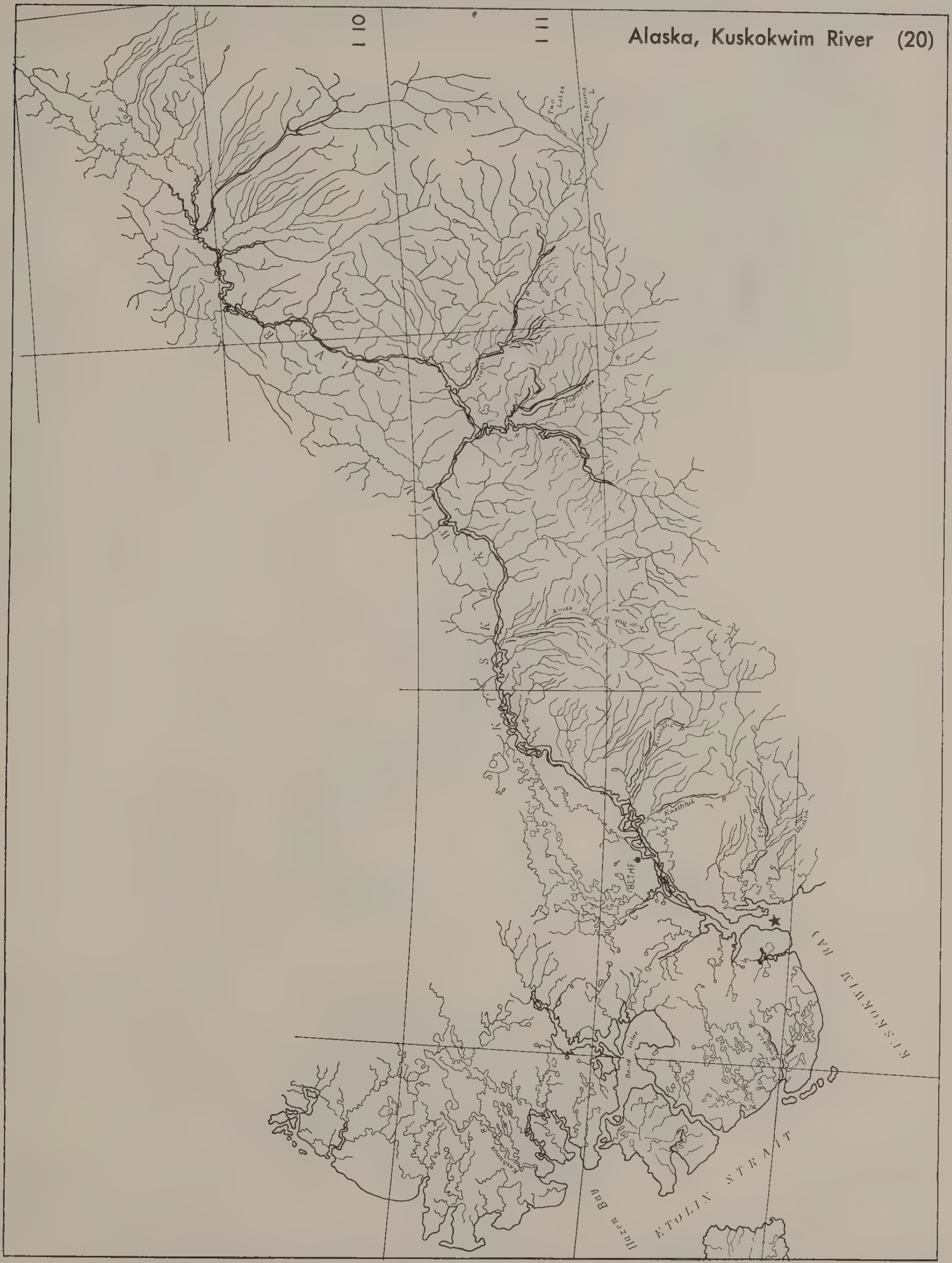
Alaska, Kuskokwim River (20)
Two Lakes
Telaquana L
R
Holitna
Hoholitna
R
KUSKOKWIM RIVER
Aniak R
Kip-Tuk R
Salmon R
Kisaralik R
Kwethluk R
Eek R
BETHEL
Baird Inlet
Kukaklik R
KUSKOKWIM BAY
Hazen Bay
ETOLIN STRAIT

FIGURE 94. Spawning grounds of chum salmon in Western Alaska (Kuskokwim River).

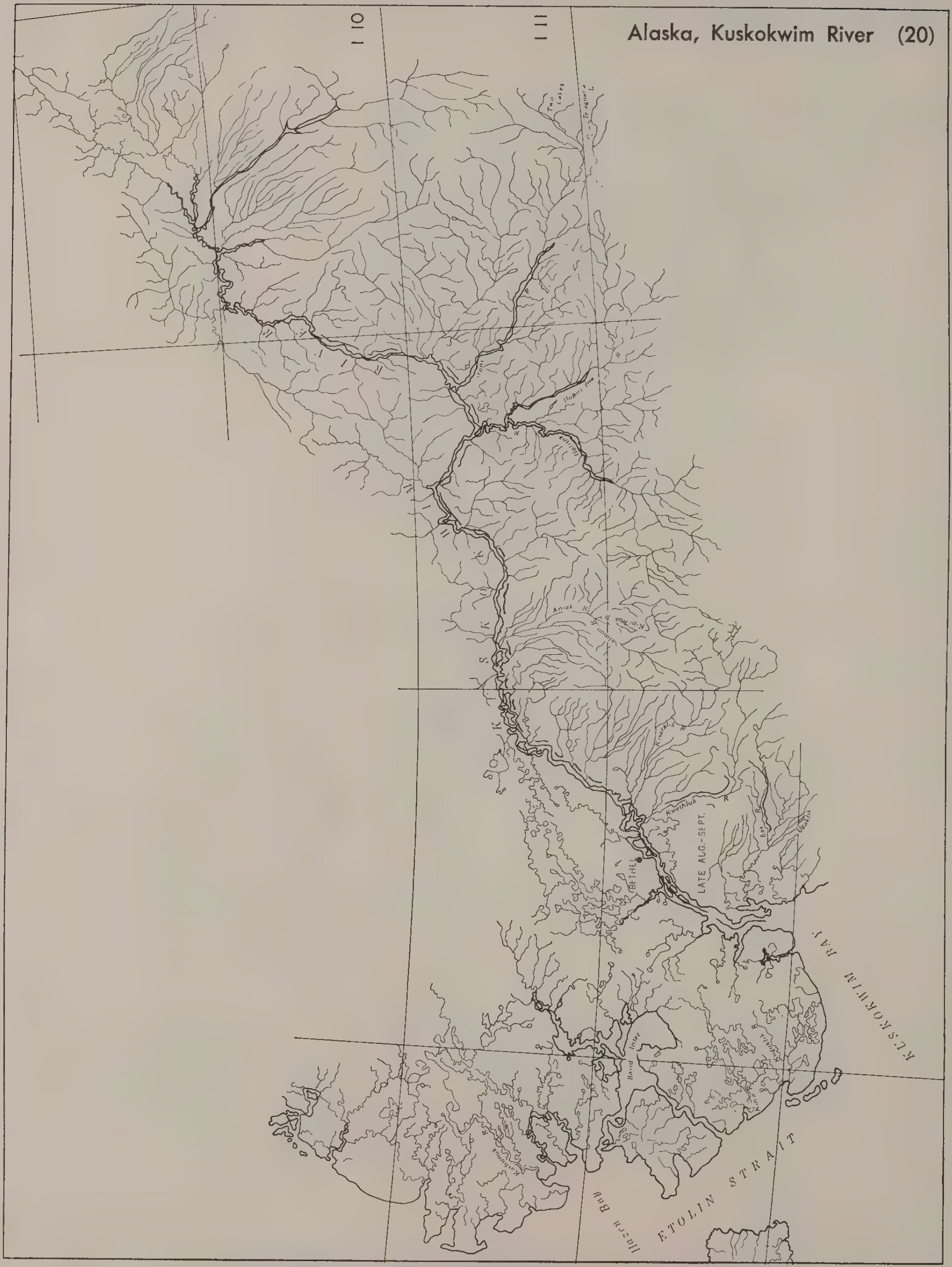
Alaska, Kuskokwim River (20)
Two Lakes
Telaquana L.
KUSKOKWIM R.
Hoholitna
Aniak R.
Kipchuk R.
Salmon R.
Kisaralik R.
Kwethluk R.
BETHEL
LATE AUG.-SEPT.
Eek R.
Ukaklik
Baird Inlet
KUSKOKWIM BAY
ETOLIN STRAIT
Hazen Bay

FIGURE 95. Spawning grounds of coho salmon in Western Alaska (Kuskokwim River).

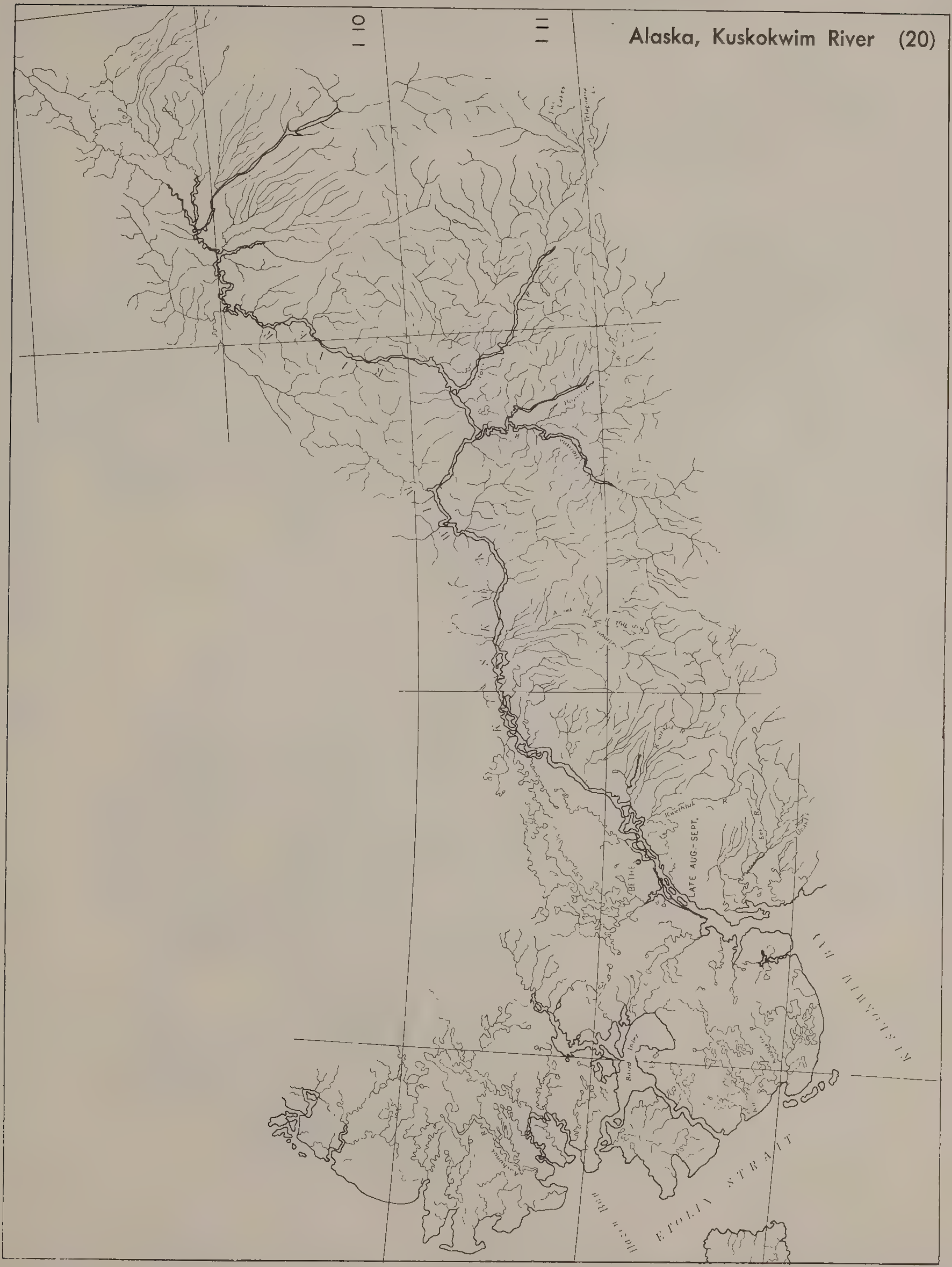
Alaska, Kuskokwim River (20)
Kwethluk R
LATE AUG.-SEPT.
BETHEL
ETOLIN STRAIT

Figure 96. Spawning grounds of pink salmon in Western Alaska (Kuskokwim River).

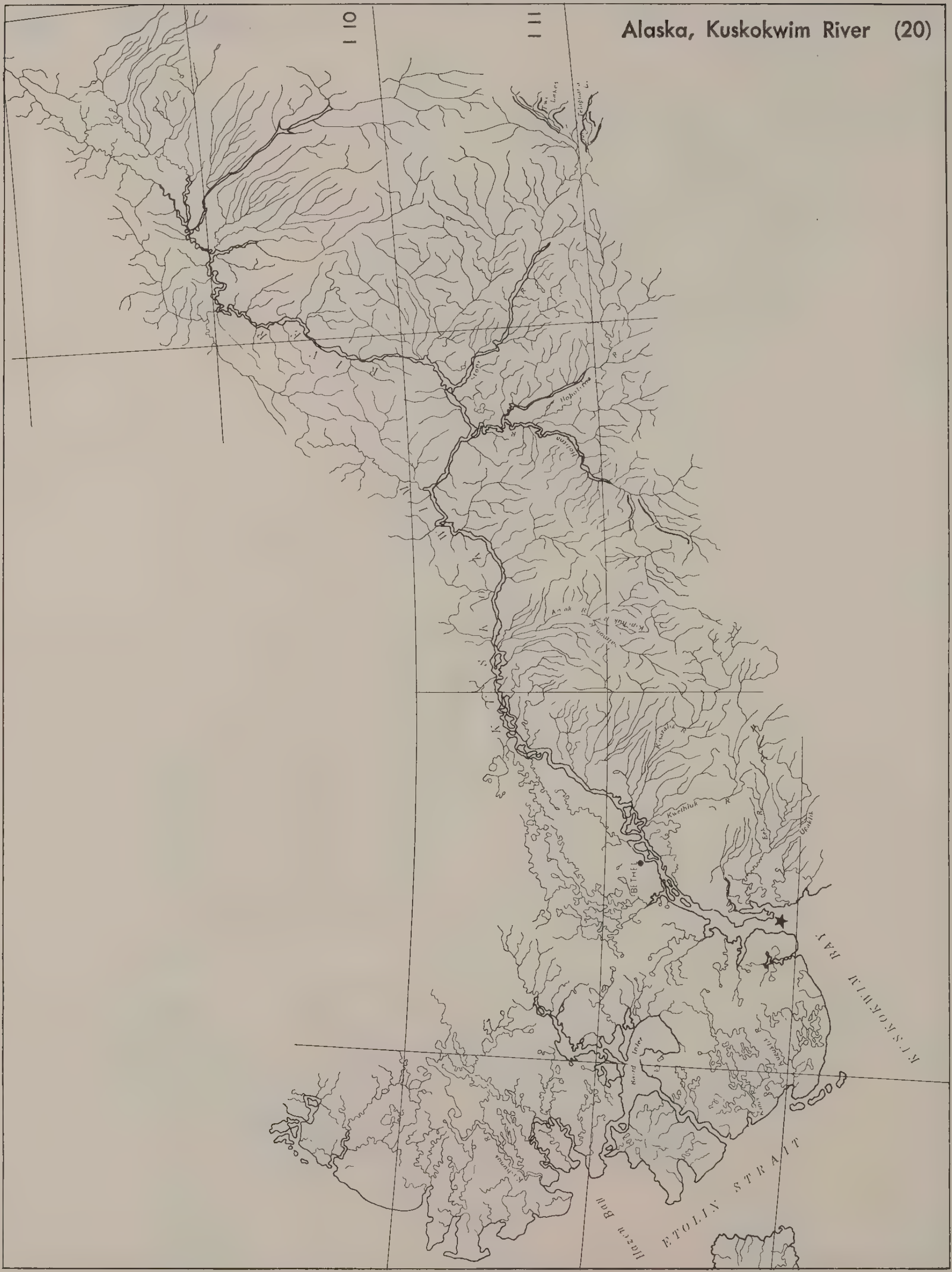
Alaska, Kuskokwim River (20)
BETHEL
Kwethluk R
KUSKOKWIM BAY
ETOLIN STRAIT
Hazen Bay

Figure 97. Spawning grounds of sockeye salmon in Western Alaska (Kuskokwim River).

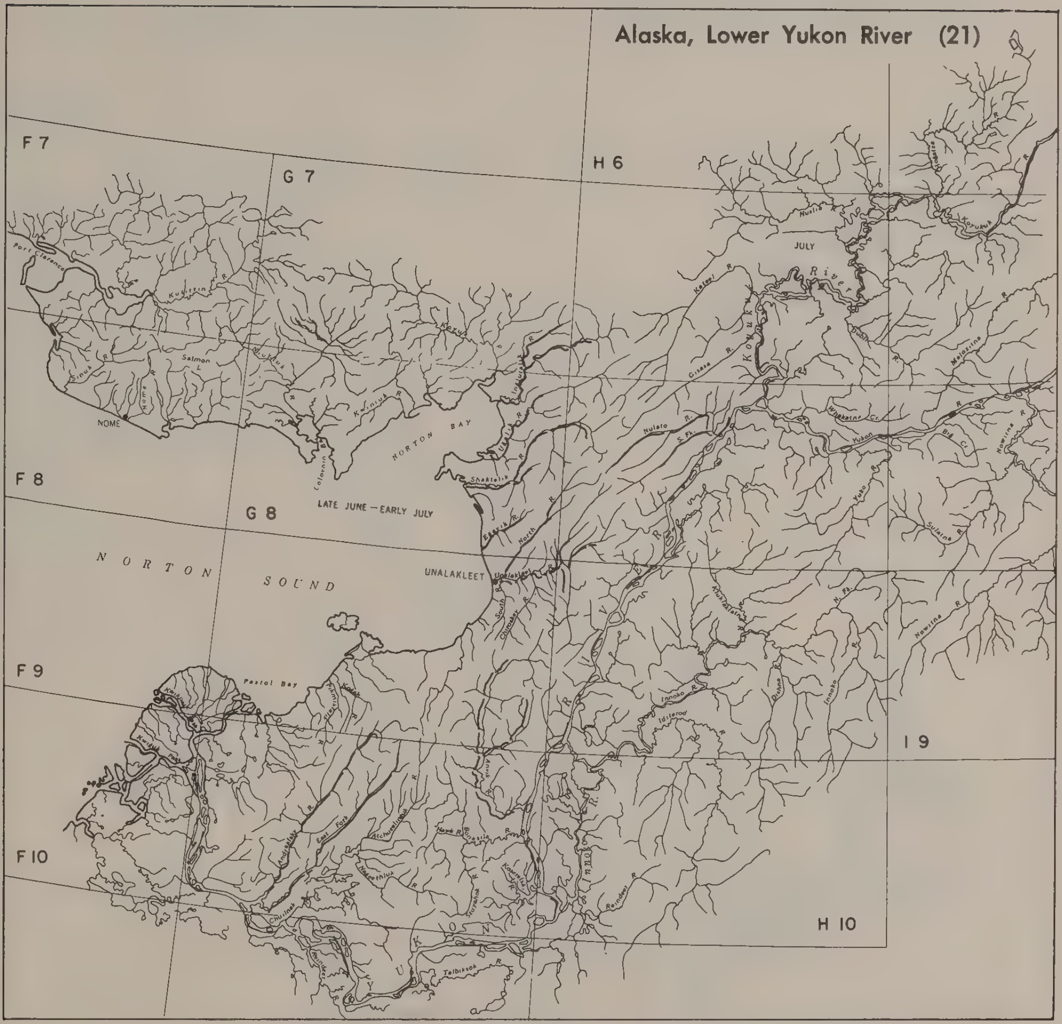
Alaska, Lower Yukon River (21)
F 7
G 7
H 6
F 8
G 8
F 9
I 9
F 10
H 10
Port Clarence
Kuzitrin R.
Sinuk R.
Salmon L.
Nome R.
NOME
NORTON BAY
LATE JUNE — EARLY JULY
Shaktolik
North R.
UNALAKLEET
Unalakleet
South R.
N O R T O N
S O U N D
Pastol Bay
JULY
Koyukuk River
Nulato R.
S. Fk.
Gisasa R.
Dulbi R.
Melozitna R.
Yukon
Big Cr.
Nowitna R.
Innoko R.
Iditarod
Y U K O N
R.

FIGURE 98. Spawning grounds of chinook salmon in Western Alaska (Lower Yukon River, Norton Sound).

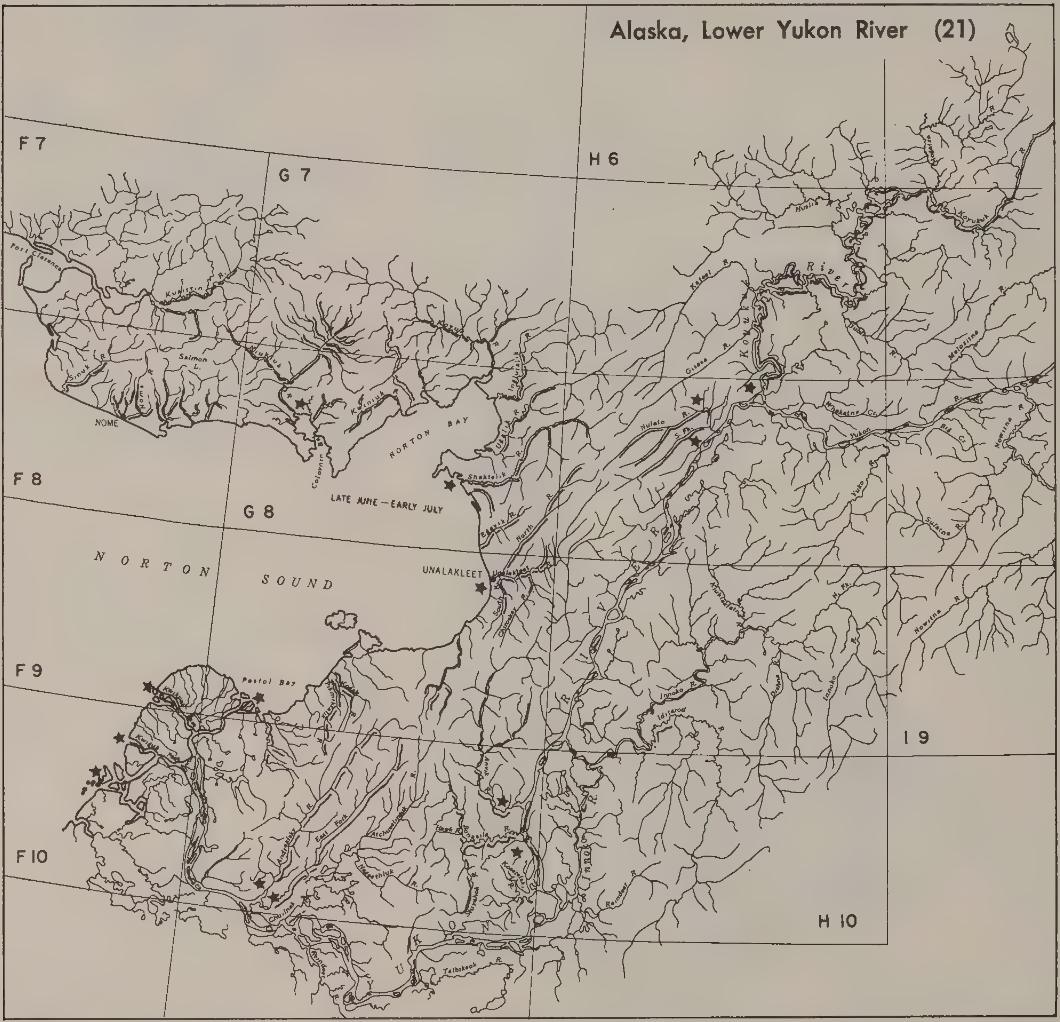
Alaska, Lower Yukon River (21)
F 7
G 7
H 6
F 8
G 8
F 9
I 9
F 10
H 10
Port Clarence
Kuzitrin R.
Sinuk R.
Salmon L.
Nome R.
NOME
Niukluk
Koyuk R.
Kwiniuk R.
Inglutalik R.
Ungalik R.
Golovnin B.
NORTON BAY
Shaktolik
LATE JUNE — EARLY JULY
Egavik R.
North R.
UNALAKLEET
Unalakleet
South R.
Chiroskey R.
NORTON
SOUND
Pastol Bay
Kwikluak
Kwiguk Pass
Pikmiktalik
Kotlik
Andreafsky R.
East Fork
Atchuelinguk R.
Nageethluk R.
Hawk R.
Bonasila R.
Anvik R.
Kaiyuh
Chulinak
Reindeer R.
Talbiksok R.
Innoko R.
Reindeer R.
Iditarod
Innoko R.
Dishna R.
Innoko R.
Khotol
Kaiyuh
Nulato R.
S. Fk.
Gisasa R.
Kateel R.
Huslia R.
Koyukuk
Koyukuk River
Dulbi R.
Melozitna R.
Whiskatne Cr.
Yukon
Yuko R.
Big Cr.
Nowitna R.
Sulatna R.
Nowitna R.
N. Fk.
Khotol R.
YUKON RIVER

Figure 99. Spawning grounds of chum salmon in Western Alaska (Lower Yukon River, Norton Sound).

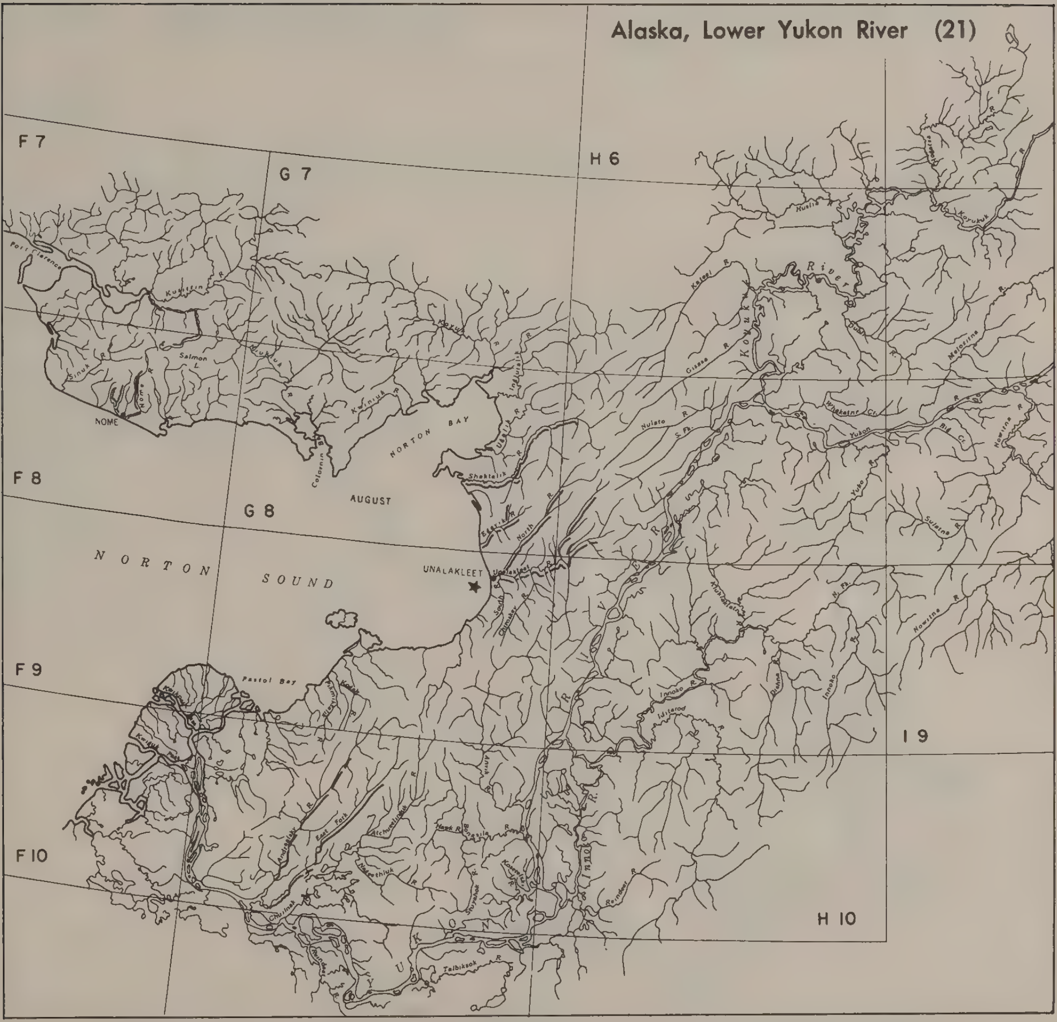
Alaska, Lower Yukon River (21)
F 7
G 7
H 6
F 8
G 8
F 9
F 10
I 9
H 10
Port Clarence
Kuzitrin R.
Sinuk R.
Salmon L.
Nome R.
NOME
Koyuk R.
Kwiniuk R.
Inglutalik R.
Ungalik R.
NORTON BAY
Shaktolik
AUGUST
North R.
Unalakleet R.
UNALAKLEET
South R.
NORTON SOUND
Pastol Bay
Andreafsky R.
East Fork
Anvik R.
Hawk R.
Innoko R.
Reindeer R.
Talbiksok R.
YUKON R.
Huslia R.
Koyukuk River
Gisasa R.
Nulato R.
S. Fk.
Melozitna R.
Big Cr.
Nowitna R.
Sulatna R.
Iditarod
Dishna R.
N. Fk.

FIGURE 100. Spawning grounds of coho salmon in Western Alaska (Lower Yukon River, Norton Sound).

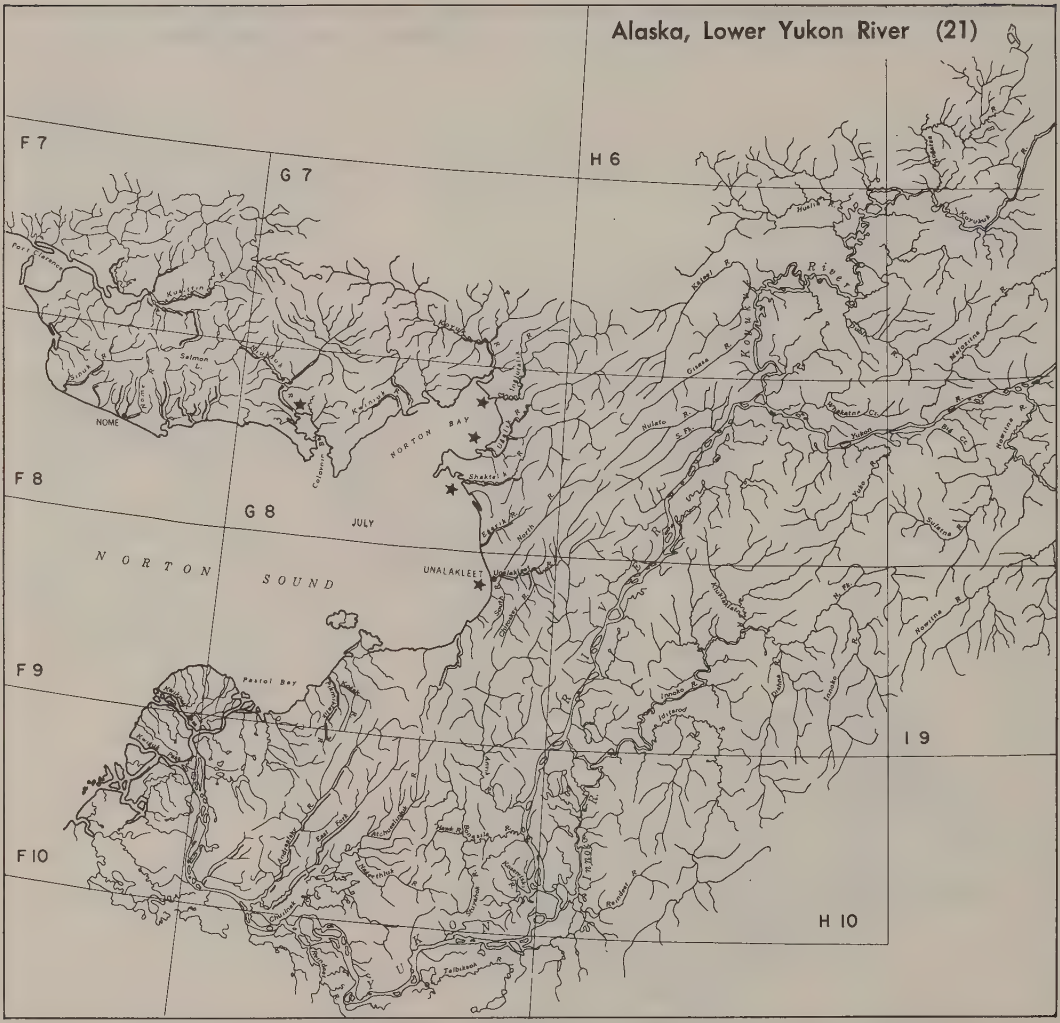
Alaska, Lower Yukon River (21)
F 7
G 7
H 6
F 8
G 8
F 9
F 10
H 10
I 9
Port Clarence
Kuzitrin R.
Sinuk R.
Nome R.
Salmon L.
NOME
Niukluk
Koyuk R.
Inglutalik R.
Kwiniuk R.
Golovnin B.
NORTON BAY
Ungalik R.
Shaktolik R.
Egavik R.
North R.
JULY
NORTON SOUND
UNALAKLEET
Unalakleet R.
South R.
Chiroskey R.
Pastol Bay
Pikmiktalik
Kotlik
Kwikluak Pass
Andreafsky R.
East Fork
Atchuelinguk R.
Nagerthluk R.
Hawk R.
Bonasila R.
Anvik R.
Stuyahok R.
Kovenlik R.
Chulinak
Reindeer R.
Talbiksok R.
Y U K O N
R I V E R
Innoko R.
Iditarod R.
Dishna R.
N. Fk.
Reindeer R.
Khotol R.
Kaiyuh
Huslia R.
Kateel R.
Koyukuk River
Hodzana
Gisasa R.
Nulato R.
S. Fk.
Dulbi R.
Melozitna R.
Whisky Cr.
Yukon
Big Cr.
Nowitna R.
Sulatna R.
Yuko R.
Nowitna R.

FIGURE 101. Spawning grounds of pink salmon in Western Alaska (Lower Yukon River, Norton Sound).

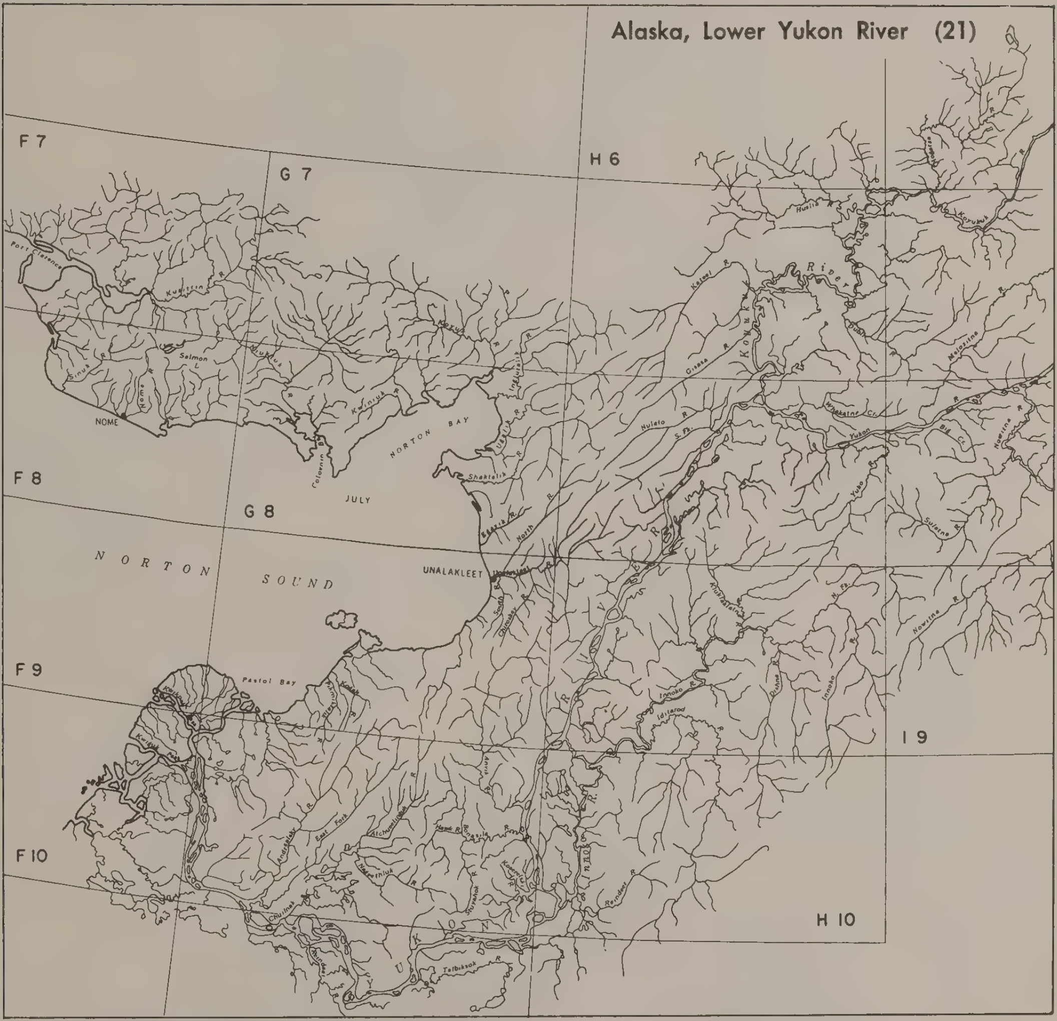
Alaska, Lower Yukon River (21)
F 7
G 7
H 6
F 8
G 8
F 9
F 10
I 9
H 10
Port Clarence
Kuzitrin R
Sinuk R
Salmon L
Nome R
NOME
Niukluk
Kwiniuk R
Koyuk R
Inglutalik
Ungalik R
Golovnin Bay
NORTON BAY
JULY
Shaktolik
Egavik R.
North R.
UNALAKLEET
Unalakleet R
South R.
Chiroskey R
N O R T O N
S O U N D
Pastol Bay
Kwikluak
Kwiguk Pass
Kotlik
Andreafsky R
East Fork
Atchuelinguk
Nageethluk R
Chulinak
Reindeer R
Talbiksok R
Anvik R
Kaiyuh
Bonasila R
Kozenik R
Innoko
Reindeer R
Y U K O N
Y U K O N R I V E R
Kateel R
Gisasa R
Koyukuk
Huslia R
Koyukuk River
Dulbi R
Melozitna R
Nulato R
S. Fk.
Whiskeine Cr.
Yukon R
Big Cr.
Nowitna R
Yuko R
Sulatna R
Khotol
Kluklaklatna
N. Fk.
Innoko R.
Iditarod R
Dishna R
Innoko R
Nowitna R

Figure 102. Spawning grounds of sockeye salmon in Western Alaska (Lower Yukon River, Norton Sound).

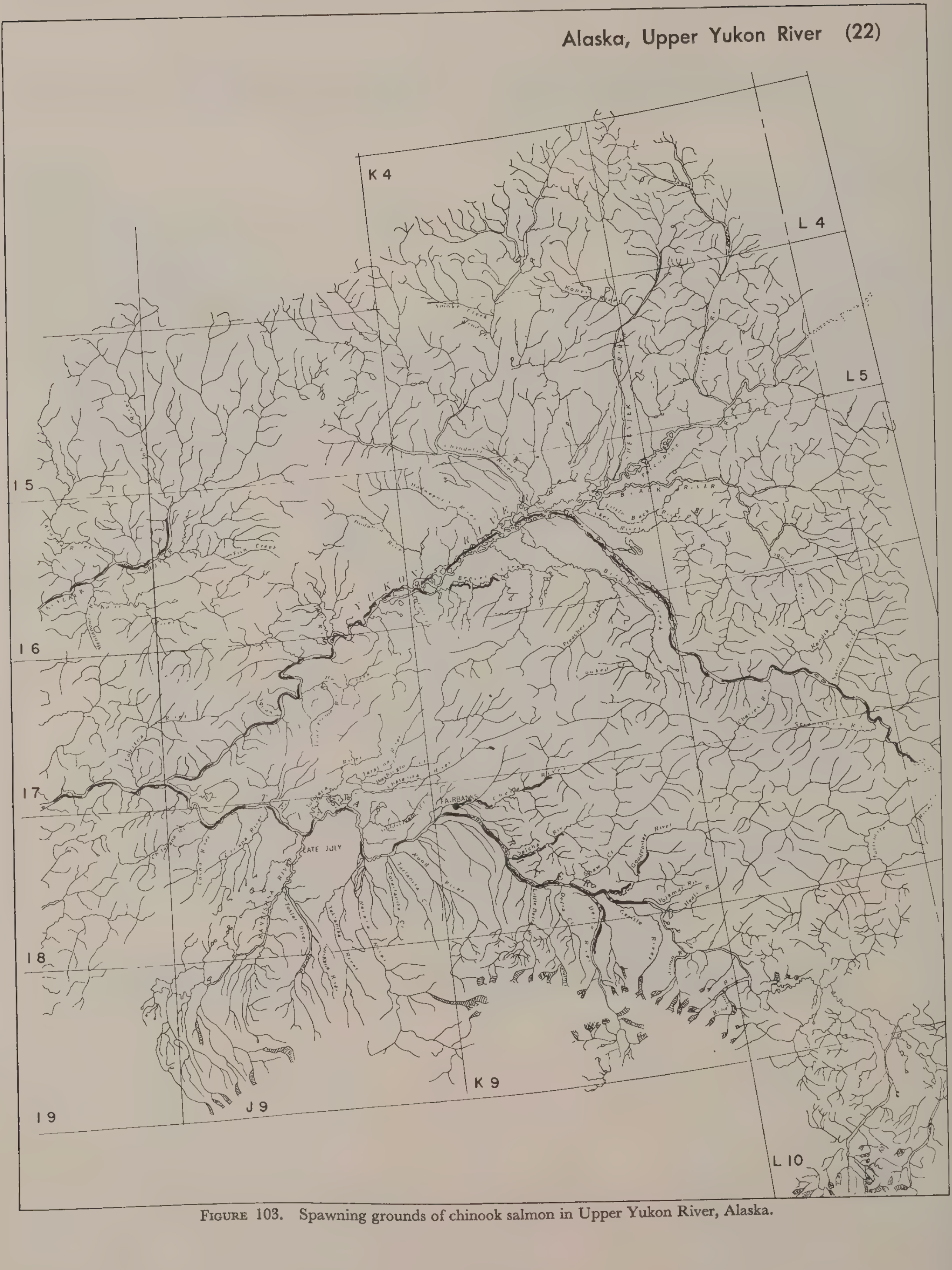
Alaska, Upper Yukon River (22)
K 4
L 4
L 5
I 5
I 6
I 7
I 8
I 9
J 9
K 9
L 10
YUKON RIVER
BLACK RIVER
FAIRBANKS
LATE JULY

FIGURE 103. Spawning grounds of chinook salmon in Upper Yukon River, Alaska.

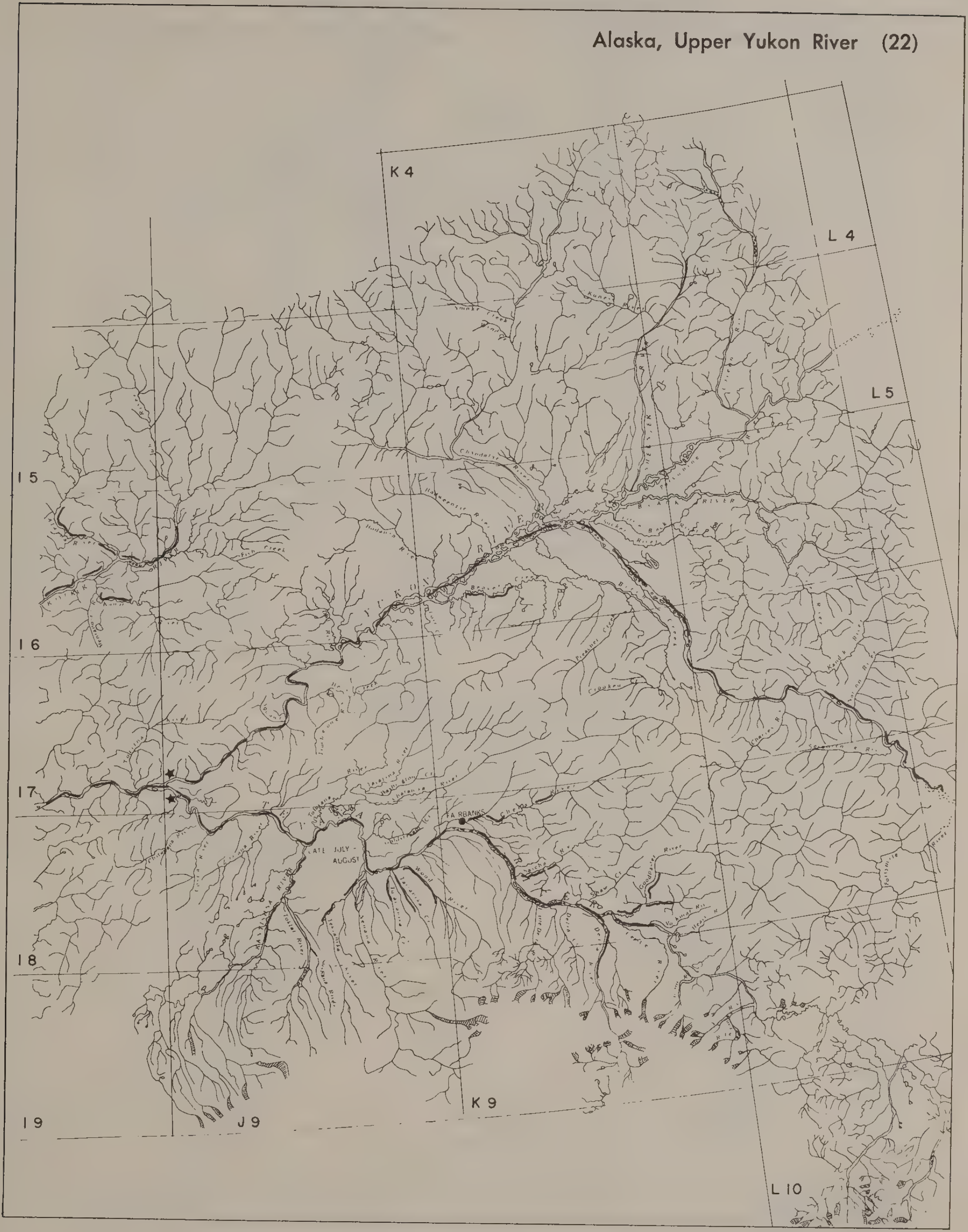
Alaska, Upper Yukon River (22)
K 4
L 4
L 5
I 5
I 6
I 7
I 8
I 9
J 9
K 9
L 10
YUKON RIVER
Chandalar River
Porcupine
BLACK RIVER
Beaver Cr.
Birch Creek
Crooked Cr.
Charley R.
Kandik River
Fish Creek
Hodzana River
TANANA
FAIRBANKS
LATE JULY - AUGUST
Chena River
Salcha River
Goodpaster River
Shaw Cr.
Delta River
Wood River
Nenana River
Totatlanika River
Tekanika River
Kantishna River
Toklat River
Washington Cr.
Chatanika River
Tolovana River

FIGURE 104. Spawning grounds of chum salmon in Upper Yukon River, Alaska.

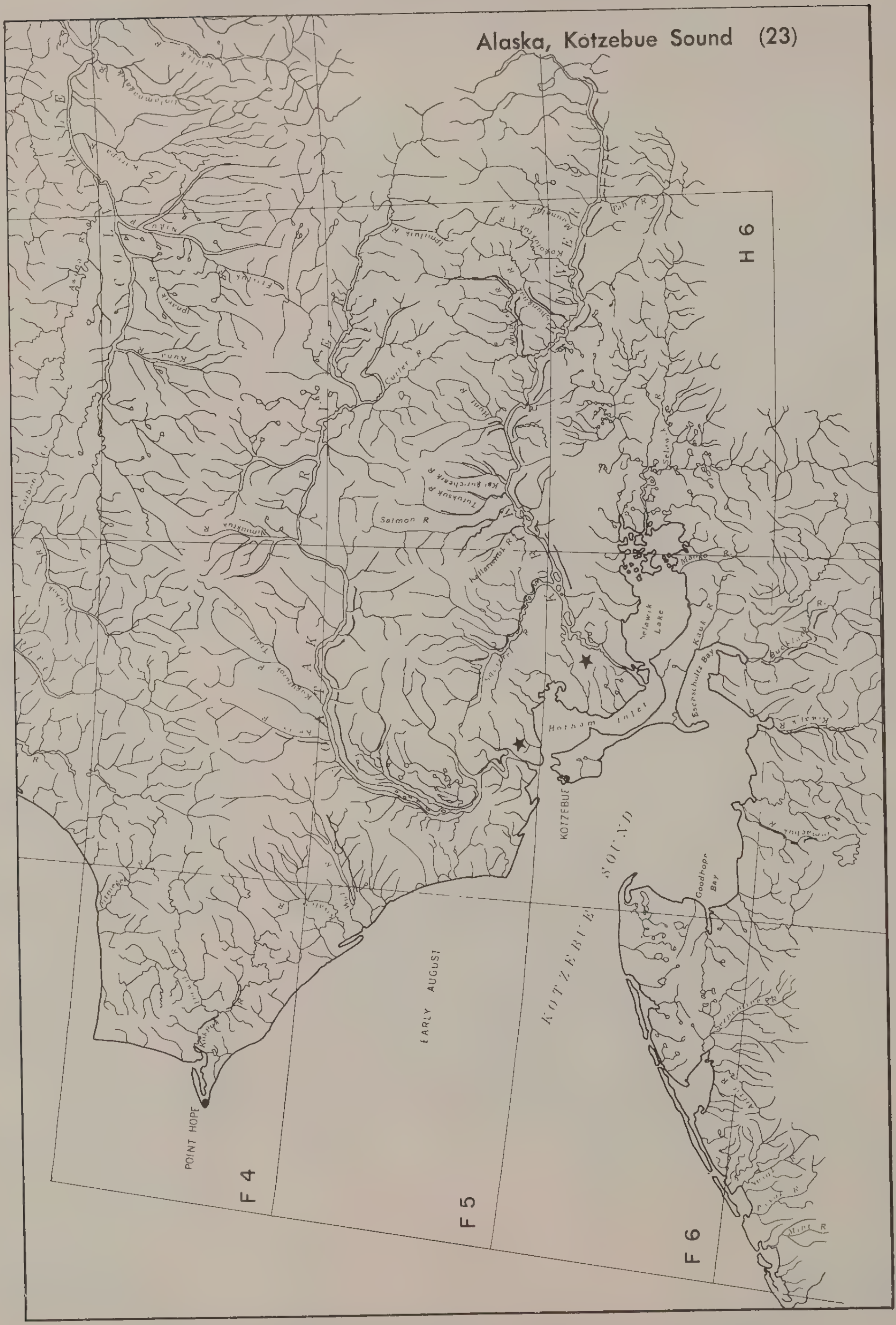
Alaska, Kotzebue Sound (23)
H 6
F 4
F 5
F 6
Killik R
Kuna R
Nigu R
Etivluk R
Ipnavik R
Ipmiluik R
Cutler R
Hunt R
Salmon R
Tutuksuk R
Kai Burichearh R
Nimiuktuk R
Kukpuk R
Kallarichuk R
Selawik R
Mangoak R
Selawik Lake
Kauk R
Buckland R
Eschscholtz Bay
Hotham Inlet
KOTZEBUE
KOTZEBUE SOUND
Goodhope Bay
Kiwalik R
Inmachuk R
Serpentine R
Arctic R
Nuluk R
Pinnik R
Mint R
EARLY AUGUST
POINT HOPE
Kukpuk R
COLVILLE RIVER
NOATAK RIVER
KOBUK RIVER

Figure 105. Spawning grounds of chum salmon in Western Alaska (Kotzebue Sound).

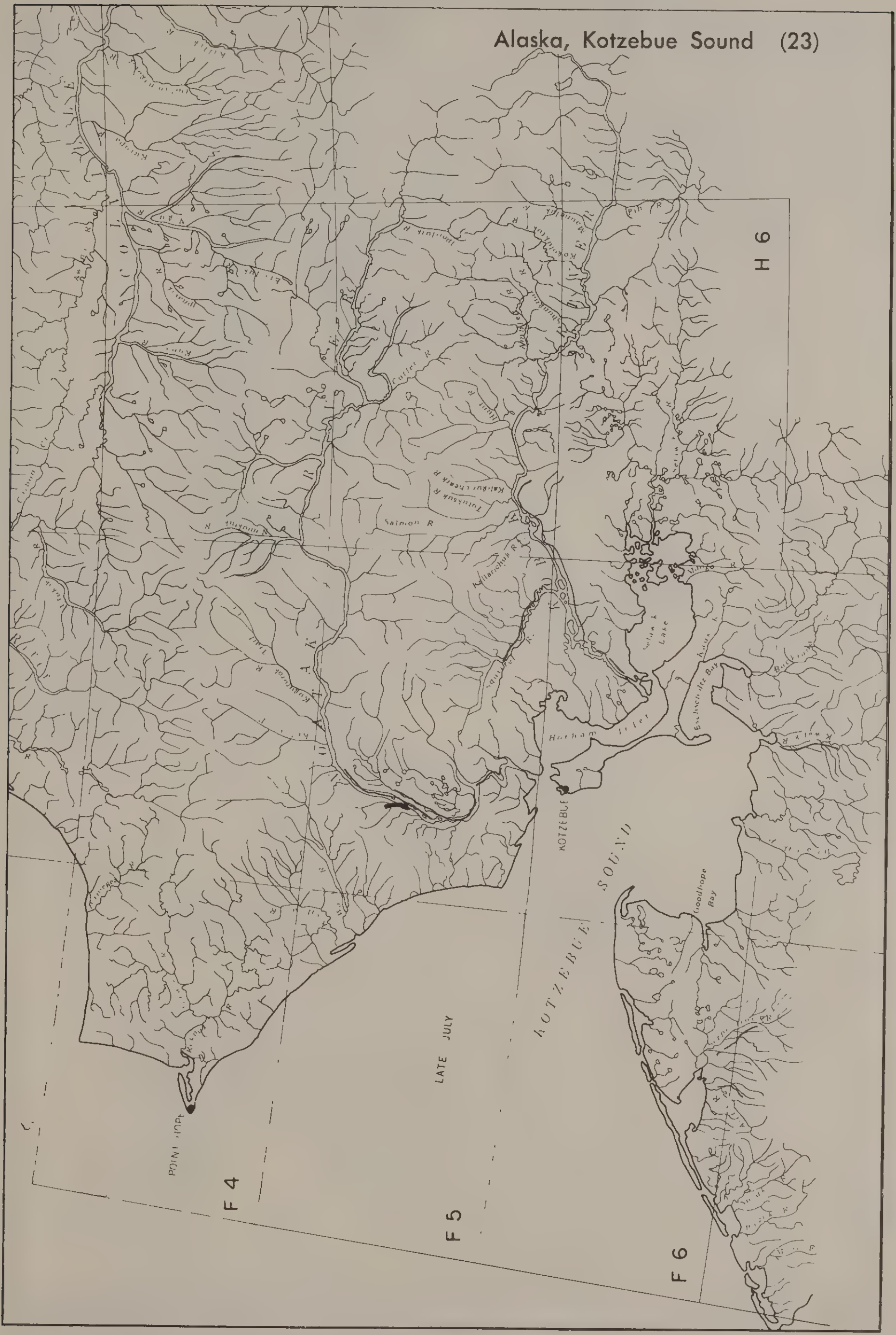
Alaska, Kotzebue Sound (23)
H 6
Salmon R
Hotham Inlet
Selawik Lake
Eschscholtz Bay
Goodhope Bay
KOTZEBUE
KOTZEBUE SOUND
LATE JULY
POINT HOPE
F 4
F 5
F 6

FIGURE 106. Spawning grounds of pink salmon in Western Alaska (Kotzebue Sound).

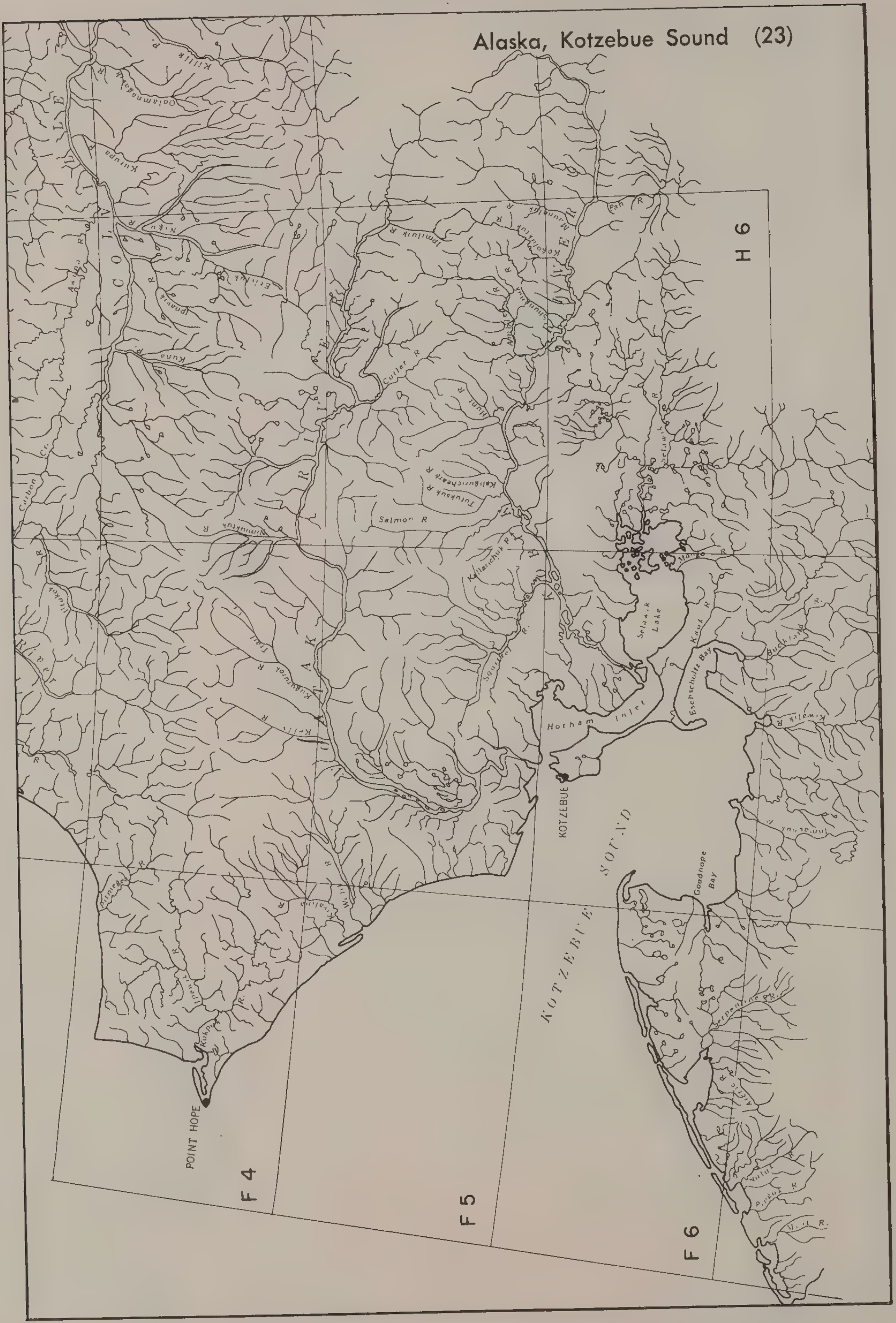
Alaska, Kotzebue Sound (23)
H 6
F 4
F 5
F 6
POINT HOPE
KOTZEBUE
KOTZEBUE SOUND
Hotham Inlet
Selawik Lake
Eschscholtz Bay
Goodhope Bay
Killik R
Kurupa R
Nigu R
Etivluk R
Kuna R
Carbon Cr.
Cutler R
Hunt R
Tutuksuk R
Salmon R
Squirrel R
Kelly R
Kugururok R
Nimiuktuk R
Pah R
Kiwalik R
Buckland
Serpentine R

FIGURE 107. Spawning grounds of sockeye salmon in Western Alaska (Kotzebue Sound).

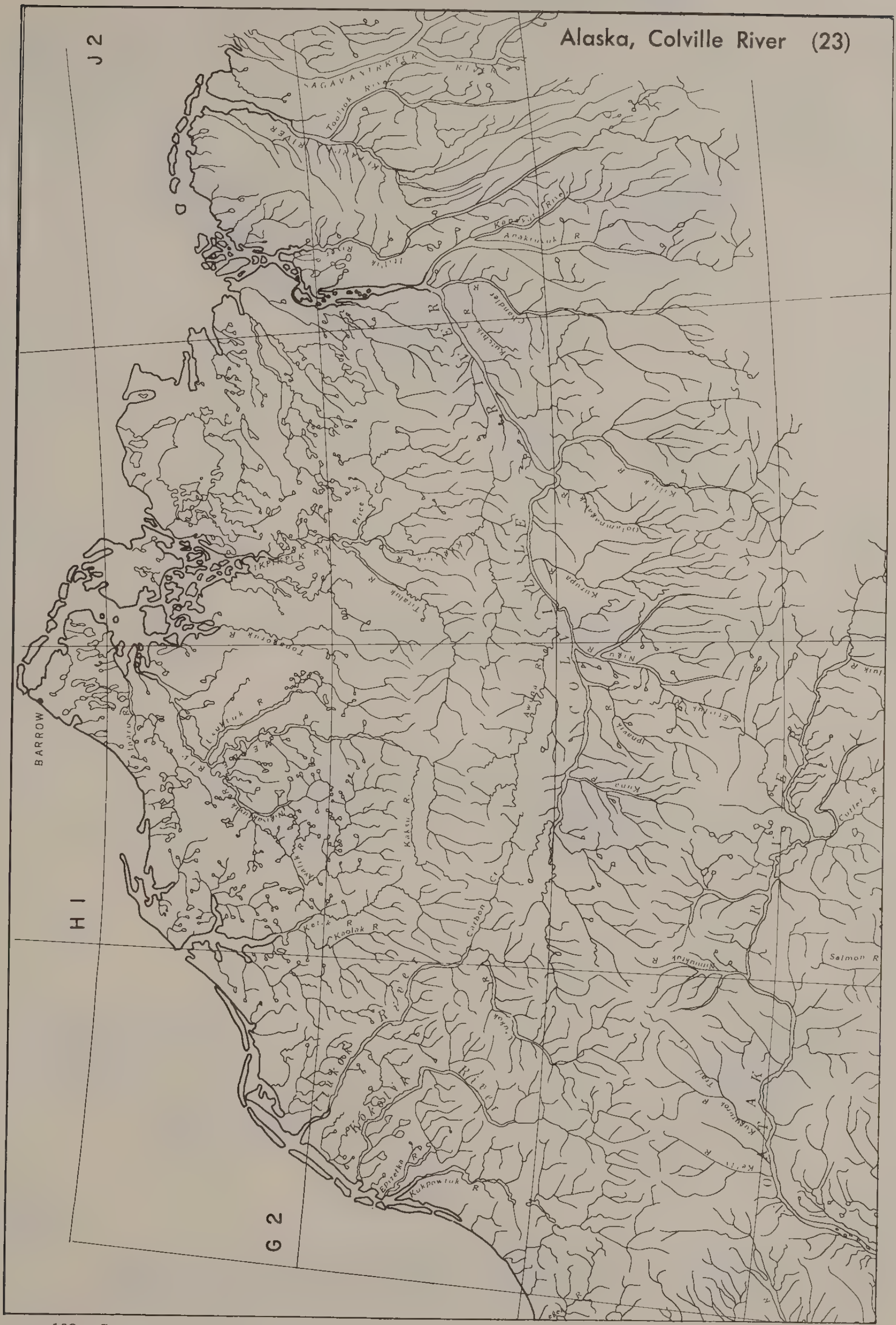
Alaska, Colville River (23)
J 2
H I
G 2
BARROW
SAGAVANIRKTOK RIVER
Toolik R.
Kuparuk River
Itkillik River
Anaktuvuk R.
Chandler R.
Killik R.
Kurupa
Nigu R.
Etivluk
Ipnavik
Kuna R.
COLVILLE RIVER
Awuna R.
Price R.
Titaluk R.
Topagoruk R.
Ikpikpuk R.
Meade R.
Inaru R.
Kugrua R.
Avalik R.
Kaolak R.
Ketik R.
Kaksu R.
Carbon Cr.
Utukok R.
Kokolik River
Epizetka R.
Kukpowruk R.
Nuka R.
Kuchiak R.
Ipnavik R.
Etivluk R.
Ikpikpuk R.
Iluk R.
Cutler R.
Salmon R.
Nimiuktuk R.
Kugururok R.
Kelly R.
NOATAK R.

Figure 108. Streams of the Arctic Coast of Alaska (Colville River). Chum and pink salmon have been reported in Arctic Coast streams, few data are available on location of spawning grounds.

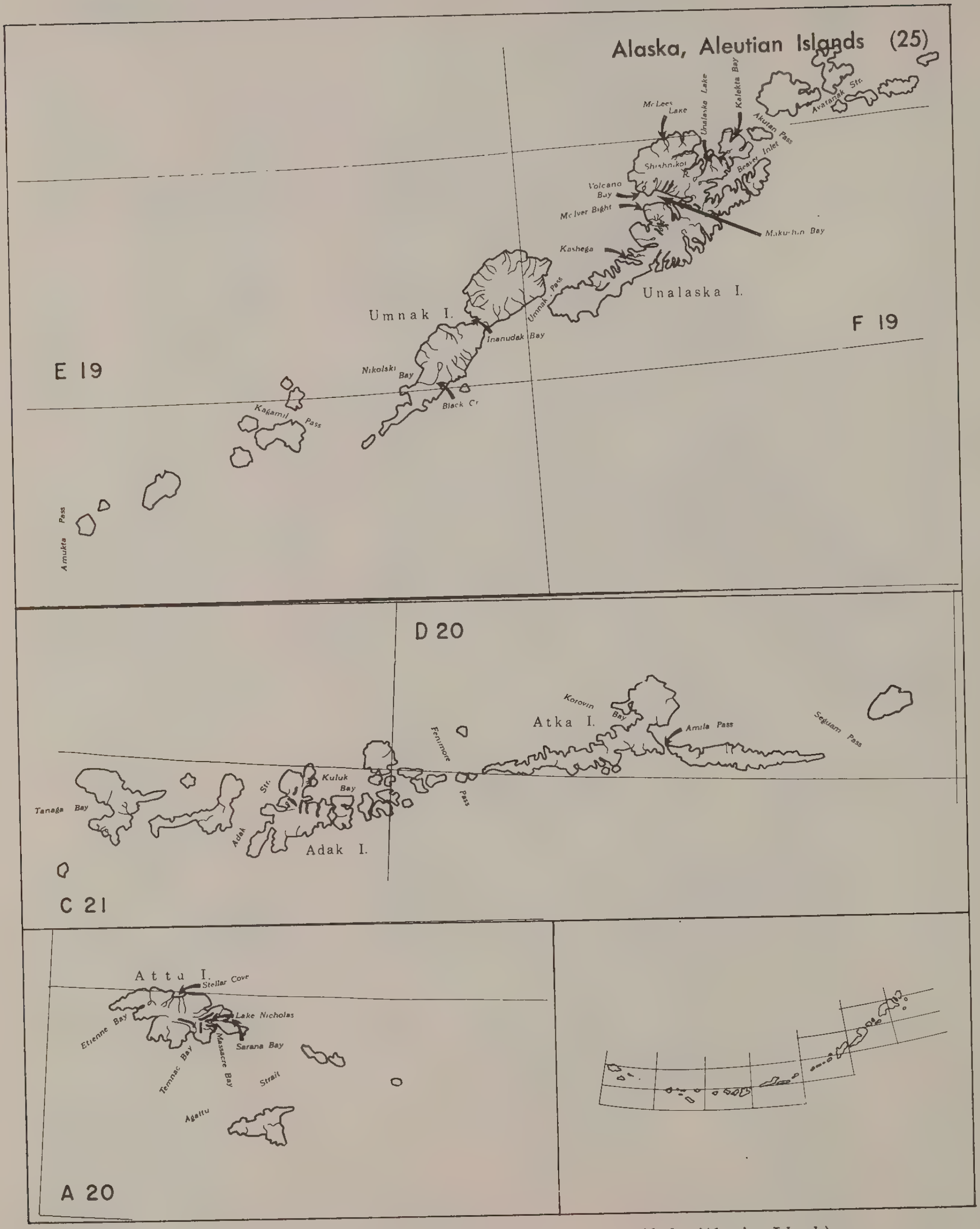
Alaska, Aleutian Islands (25)
Mc Lees Lake
Unalaska Lake
Kalekta Bay
Akutan Pass
Avatanak Str.
Beaver Inlet
Shishnikoi R
Volcano Bay
Mc Iver Bight
Makushin Bay
Kashega
Unalaska I.
Umnak Pass
Umnak I.
Inanudak Bay
Nikolski Bay
Black Cr
Kagamil Pass
Amukta Pass
E 19
F 19
D 20
Korovin Bay
Atka I.
Amlia Pass
Seguam Pass
Fenimore Pass
Kuluk Bay
Adak Str.
Adak I.
Tanaga Bay
C 21
Attu I.
Stellar Cove
Lake Nicholas
Sarana Bay
Etienne Bay
Temnac Bay
Massacre Bay
Strait
Agattu
A 20

FIGURE 109. Spawning grounds of pink salmon in Western Alaska (Aleutian Islands).

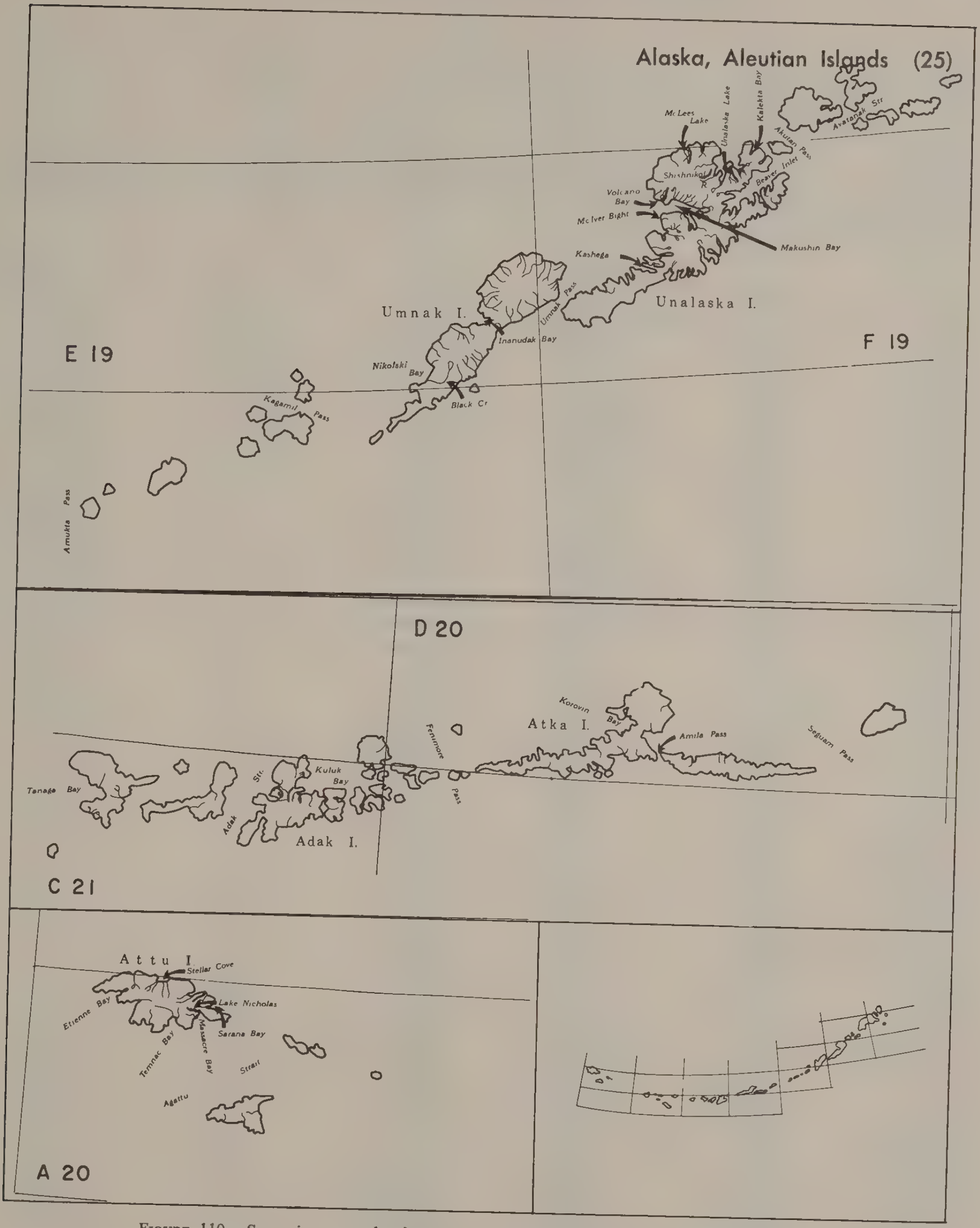
Alaska, Aleutian Islands (25)
Mc Lees Lake
Unalaska Lake
Kalekta Bay
Avatanak Str
Akutan Pass
Shishnikof R
Beaver Inlet
Volcano Bay
Mc Iver Bight
Makushin Bay
Kashega
Umnak Pass
Unalaska I.
Umnak I.
Inanudak Bay
F 19
E 19
Nikolski Bay
Black Cr
Kagamil Pass
Amukta Pass
D 20
Korovin Bay
Atka I.
Amila Pass
Seguam Pass
Fenimore Pass
Kuluk Bay
Adak Str.
Tanaga Bay
Adak I.
C 21
Attu I.
Stellar Cove
Lake Nicholas
Etienne Bay
Sarana Bay
Temnac Bay
Massacre Bay
Strait
Agattu
A 20

FIGURE 110. Spawning grounds of sockeye salmon in Western Alaska (Aleutian Islands).

APPENDIX I

ALPHABETICAL INDEX TO RIVERS, LAKES, STREAMS, ETC.

"Location" refers to subareas of Figure 2 and grid coordinates of Figure 3 (see Tables 3 and 4 for summaries); (—) for subarea indicates that the stream is not identified on the maps. Numbers assigned to Alaskan streams are shown; these are cross-indexed in Appendix II where unnamed Alaskan streams are listed.

Name	State	Location
Aaron Cr.	Alas. WR6	(7) O-16
Abernathy Cr.	Wash.	(4) Q-26
Abiquo Cr.	Oreg.	(—) Q-27
Adak I. streams	Alas.	(25) C-21
Adams Cr.	Wash.	(—) Q-26
Addison Cr. (Attu I.)	Alas.	(25) A-20
Admiralty Cr.	Alas. E10A	(11) N-14
Afognak Riv.	Alas. 14K	(18) I-14
Agiapuk Riv.	Alas.	(—) F-7
Agulowak Riv.	Alas.	(—) H-13
Agulukpak Riv.	Alas.	(—) H-13
Ahrnklin Riv.	Alas.	(14) M-13
Aiken Cr.	Alas. K137	(—) N-17
Akalura Lake (Kodiak)	Alas.	(—) I-15
Akwe Riv.	Alas.	(14) M-13
Alagnak Riv.	Alas.	(20) H-I-13
Alatna Riv.	Alas.	(22) I-6
Alava Cr.	Alas. K67	(7) N-17
Alder Cr.	Alas.	(—) I-15
Alder Cr.	Alas. WR97	(8) N-16
Alder Cr.	Oreg.	(—) R-28
Alder Cr.	Wash.	(—) Q-24
Alec Riv.	Alas.	(—) H-16
Alec Flyum Cr. (Iliamna Lake)	Alas.	(—) I-13
Alecks Cr.	Alas. E44D	(—) N-16
Aleknagik Lake and streams (Wood River)	Alas.	(—) H-13
Alexander Cr. and Lake	Alas.	(—) J-11
Alexi Cr.	Alas.	(20) I-13
Alfred Cr.	Alas.	(—) H-16
Alfred Cr.	Alas.	(16B) K-11
Allen Cr.	Alas. 37	(—) K-12
Allen Riv. and Lake	Alas.	(—) H-12
Allison Cr.	Alas. 135	(15*) K-11
Alpine Cr.	Calif.	(—) Q-34
Alsea Riv.	Oreg.	(2) P-Q-28
Alsek Riv. and Lake	Alas.	(14) M-12-13
Alturas Lake	Idaho	(—) S-29
Amakdedori Cr.	Alas.	(16C) I-13
Amanka Lake	Alas.	(20) H-13
Ambler Riv.	Alas.	(23) H-5
American Cr.	Alas.	(—) I-14
American Riv.	Alas.	(—) F-7
American Riv.	Alas. 20K	(18) I-15
American Riv.	Calif.	(1) Q-34
American Riv.	Wash.	(—) Q-26
Amherst Riv.	Alas. 320	(15*) K-11
Anaktuvuk Riv.	Alas.	(23*) J-3-4
Anan[1] Cr.	Alas. WR15	(7) O-16
Anan Bay Cr.	Alas. WR14	(—) O-16
Anchor Cr.	Alas. K51	(—) O-16
Anchor Riv.	Alas.	(16A) J-13
Anchorage Cr.	Alas. 271	(—) K-12
Anderson Cr.	Alas. 667	(—) J-12
Anderson Cr.	Wash.	(—) Q-24
Andreafsky Riv.	Alas.	(21) G-10
Andrew Cr.	Alas. WR3-1	(7) N-16
Aniak Riv.	Alas.	(20*) H-11
Aniakchak Riv.	Alas.	(—) H-16
Ankau Cr.	Alas.	(14) M-13
Ano Nuevo Cr.	Calif.	(—) Q-35
Antelope Cr.	Calif.	(1) Q-32
Antlen Riv.	Alas.	(14) M-13
Antler Riv.	Alas.	(12) N-14
Anton Larson Cr.	Alas. 106K	(18) I-15
Anvik Riv.	Alas.	(21) G-10
Apollo Cr.	Alas.	(—) G-17
Applegate Riv.	Oreg.	(2) Q-30
Arctic Riv.	Alas.	(23) F-6-7
Arolik Lake	Alas.	(20) G-13
Ashton Cr.	Alas. 668	(—) J-12
Ashton Cr.	Wash.	(—) Q-24
Asotin Cr.	Wash.-Oreg.	(—) R-26
Atchueelinguk Riv.	Alas.	(21) G-10
Auburn Cr.	Oreg.	(—) R-28
Audrey Cr.	Alas. 695	(—) K-12
Auke Lake	Alas.	(12) N-14
Aurel Lake (Kodiak)	Alas.	(—) I-15
Avalik Riv.	Alas.	(23*) H-2-3
Avery Riv.	Alas. 314	(—) K-11
Awuna Riv.	Alas.	(23*) H-I-3
"B" Cr.	Alas.	(—) I-15
Babcock Cr.	Alas.	(16A) J-13
Bacabara Cr.	Alas.	(—) H-15
Backyard Cr.	Alas. 224	(—) K-12
Badger Cr.	Alas. K25	(—) O-17
Badger Cr.	Oreg.	(—) Q-28

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[1] Shown as "Ana" on map.

Continued ...

Appendix I. Continued.

Name	State	Location
Baggage Riv.	Alas.	(—)M-3
Bainbridge Cr.	Alas. 630	(—)J-12
Baker Cr.	Oreg.	(—)P-30
Baker Riv.	Wash.	(—)Q-24
Bakewell Cr.	Alas. K33	(—)O-17
Banzer Cr.	Alas. 96	(—)K-12
Barabara Cove Cr.	Alas. 103K	(18)I-15
Baralof Harbor Cr.	Alas.	(—)G-17
Barbara Cr.	Alas.	(—)H-16
Bare Cr.	Alas. 126K	(—)I-15
Barling Riv.	Alas. 46K	(18)I-15
Barnes Cr.	Alas. 697	(—)K-12
Barnes Lake	Alas.	(—)N-16-17
Barrie Cr.	Alas. WR65	(10)N-16
Barrier Cr.	Alas. K44-4	(7)O-17
Bartlett Riv.	Alas. I27	(13)N-14
Basin Cr.	Alas. K44-	(—)O-17
Bates Cr.	Alas. 833	(—)K-12
Bates Lake and Riv.	Alas.	(—)M-12
Battle Cr.	Calif.	(1)Q-32
Battle Riv.	Alas.	(—)I-13
Baumann's Cr.	Alas. 102K	(18)I-15
Bay of Isles Cr.	Alas.	(—)I-14
Bayside Cr.	Calif.	(—)P-Q-32
Beach Riv.	Alas. 775	(15*)K-12
Beagle Cr.	Oreg.	(—)R-28
Beanard Cr.	Alas.	(—)K-11
Bear Cr.	Alas.	(—)H-15
Bear Cr. (Iliamna Lake)	Alas.	(—)I-13
Bear Cr.	Alas.	(16A)J-12
Bear Cr.	Alas. E10	(11)N-14
Bear Cr.	Alas. I17A	(—)N-15
Bear Cr.	Alas. WC61	(—)N-16
Bear Cr.	Calif.	(—)Q-32
Bear Cr.	Idaho	(—)S-26
Bear Cr.	Oreg.	(—)P-29
Bear Cr.	Oreg.	(—)Q-28
Bear Cr.	Oreg.	(—)Q-30
Bear Cr.	Wash.	(—)Q-25
Bear Cr.	Wash.	(—)R-26
Bear Cr.	Wash.	(—)Q-27
Bear Lake and Riv.	Alas.	(19)G-16-17
Bear Lake	Alas.	(16A)J-12
Bear Cape Cr.	Alas. 816	(—)K-12
Bear Stand Cr.	Alas.	(16A)J-12
Beartrap Riv.	Alas. 48	(—)K-12
Bear Valley Cr.	Idaho	(—)S-28
Beaver Cr.	Alas.	(—)F-8
Beaver Cr.	Alas.	(—)I-12
Beaver Cr.	Alas.	(—)I-14
Beaver Cr.	Alas.	(16A)J-13
Beaver Cr.	Alas.	(22)K-6
Beaver Cr.	Alas. 807	(—)K-12
Beaver Cr.	Alas. WC15	(8)N-17
Beaver Cr.	Alas. K80	(7)O-17
Beaver Cr.	Oreg.	(—)P-28
Beaver Cr.	Oreg.	(—)Q-26
Beaver Cr.	Oreg.	(—)Q-28
Beaver Cr.	Oreg.	(—)Q-28
Beaver Cr.	Oreg.	(6)R-27
Beaver Cr.	Wash.	(—)Q-26
Beaver Lake	Alas.	(—)I-12
Beaver Lake	Alas.	(—)J-11
Beaver Riv.	Alas.	(—)K-6
Becharof Cr. and Lake	Alas.	(18)H-I-14-15
Belinda Cr. (Iliamna Lake)	Alas.	(—)I-13
Bell Cr.	Alas. K81	(7)O-17
Beluga Lake and Riv.	Alas.	(16B)J-11
Bench Mark Cr.	Alas. 213	(—)K-11
Benzeman Lake	Alas.	(9)N-16
Bering Lake and Riv.	Alas.	(15)K-12
Bernard Cr.	Alas. 861	(—)K-12
Berners Riv.	Alas.	(12)N-14
Bertrand Cr.	Wash.	(—)Q-24
Bert's Cr.	Alas.	(—)H-15
Bettles Riv.	Alas. 422	(—)J-12
Beverley Lake and streams (Wood Riv.)	Alas.	(—)H-13
Big Cr. (Wide Bay)	Alas.	(18)H-15
Big Cr.	Alas.	(21)I-8
Big Cr.	Alas.	(—)I-14
Big Cr.	Alas. WR52	(10)N-16
Big Cr.	Alas. WR101	(—)N-16
Big Cr.	Calif.	(—)Q-35
Big Cr.	Idaho	(—)S-27
Big Cr.	Oreg.	(—)P-Q-29-30
Big Cr.	Oreg.	(4)Q-26
Big Cr.	Oreg.	(—)R-28
Big Cr.	Oreg.	(—)R-28
Big Cr.	Wash.	(—)P-25
Big Lake	Alas.	(16B)J-11
Big Riv.	Alas. 108K	(18)I-14
Big Riv.	Calif.	(1)Q-33
Big Riv.	Wash.	(—)P-24
Big Fall Cr.	Oreg.	(—)Q-29
Big Goat Cr.	Alas. K39	(7)O-17
Big Indian Riv.	Alas.	(16B)J-12
Big John Cr.	Alas. E34A	(—)N-16
Big Kitoi Lake Cr.	Alas. 8K	(18)I-14
Big Mud Riv.	Alas.	(—)I-8
Big Pistol Cr.	Idaho	(—)S-28
Big Salmon Riv.	Alas.	(—)N-11
Big White Salmon[2] Riv.	Wash.	(4)Q-27
Bill Cr.	Oreg.	(—)P-29
Billies Hole	Alas. 218	(—)K-12
Billings Riv.	Alas. 438	(—)J-12
Billy Cr.	Alas.	(16B)K-11
Bingham Cr.	Wash.	(—)Q-25
Birch Cr.	Alas.	(—)J-10

[2] Shown as “White Salmon R.” on map.

Continued ...

APPENDIX I. Continued.

Name	State	Location
Birch Cr.	Alas.	(22) K-6-7
Bird Cr.	Alas.	(16B) J-11-12
Birthday Cr.	Alas.	(—) H-16
Bishop Cr. (Balboa Bay)	Alas.	(19) G-17
Bishop Cr. and Lake	Alas.	(16B) J-12
Bjorne Cr.	Alas. 665	(15*) K-12
Black Cr.	Alas.	(25) E-19
Black Cr. (Ugashik Lake)	Alas.	(—) H-15
Black Cr. and Lake	Alas.	(19) H-16
Black Cr.	Alas. 107	(—) K-12
Black Cr.	Alas. K27	(—) O-17
Black Lake	Wash.	(—) Q-25
Black Riv.	Alas.	(22) K-L-6
Black Riv.	Alas.	(—) M-15
Black Riv.	Wash.	(—) Q-26
Black Bear Cr.	Alas. 276	(—) K-12
Black Bear Cr.	Alas. K66	(7) N-17
Black Hills Cr.	Alas.	(19) G-17
Blackstone Cr.	Alas. 451	(—) J-12
Bladgett Lakes	Alas.	(16B) J-11
Bligh Cr.	Alas. 108	(15*) K-12
Blind Slough	Alas.	(—) N-16
Blue Cr. (Ugashik Lake)	Alas.	(—) H-15
Blue Cr.	Calif.	(—) Q-31
Blue Lake	Alas.	(16C) I-12
Blue Lake	Alas.	(—) L-12
Blue Riv.	Oreg.	(—) Q-28
Blue Bill Lake	Alas.	(—) G-17
Blueberry Cr.	Alas.	(19) H-16
Blue Stone Cr.	Alas.	(—) F-7
Bluff Cr.	Alas. 868	(—) K-12
Boardwalk Cr.	Alas. 104	(—) K-12
Bogachiel Riv.	Wash.	(3) P-25
Bogus Mt. Cr.	Calif.	(1) Q-31
Boise Cr.	Wash.	(—) Q-25
Boise Riv.	Idaho	(6) R-29
Bonasila Riv.	Alas.	(21) G-10
Borodkin Cr.	Alas. 100	(—) K-12
Bostwick Cr.	Alas. K114	(7) O-17
Boulder Cr.	Alas.	(16B) J-11
Boulder Cr.	Alas. K40	(—) O-17
Boulder Cr.	Oreg.	(—) Q-28
Boulder Cr.	Wash.	(—) Q-24
Boundary[3] Cr.	Alas.	(12) N-14
Bow Cr.	Alas.	(16C) I-13
Bowser Cr.	Alas.	(16C) I-13
Bradfield Riv., N. and E.	Alas. WR11 and WR12	(7) N-16
Bradley Riv.	Alas.	(16A) J-13
Breakwater Cr.	Alas. K17	(—) O-18
Bremner Riv.	Alas.	(15) K-L-11-12
Bridge Cr.	Alas. 105	(—) K-12
Brizgaloff Cr.	Alas. 623	(—) J-12
Brooks Cr. (Nos. 1 and 2) (Brooks Lake)	Alas.	(—) H-14
Brooks Lake and Riv.	Alas.	(18) H-I-14
Brown Cr.	Alas.	(16C) I-13
Brown Cr.	Alas. 103	(—) K-12
Brown Bear Cr.	Alas. 821	(—) K-12
Brown's Lagoon Cr.	Alas. 93K	(18) I-15
Buckland Riv.	Alas.	(23) G-6-7
Bumping Riv.	Wash.	(5) Q-26
Bunker Cr.	Wash.	(—) Q-26
Burnt Riv.	Oreg.	(—) R-28
Buschmann Cr.	Alas. K22-1	(—) O-17
Bush Cr.	Alas. K112	(—) O-17
Bush Cr.	Idaho	(—) S-26
Bushby Cr.	Alas. 113	(15*) K-12
Buskin Cr.	Alas. 17K	(18) I-15
Buster Cr.	Alas. WR98	(8) N-16
Butte Cr.	Calif.	(1) Q-33
Butte Cr.	Oreg.	(—) Q-27
Butte Cr.	Oreg.	(—) Q-30
Butte Cr.	Oreg.	(—) R-27
"C" Cr. (Ugashik Lake)	Alas.	(—) H-15
Cabin Cr. (Iliamna Lake)	Alas.	(—) I-13
Cabin Cr.	Alas. 747	(—) K-12
Cabin Cr.	Alas. K169	(8) N-17
Cabin Cr.	Alas. K35	(7) O-17
Calapooya Riv.	Oreg.	(4) Q-28
Calaveras Riv.	Calif.	(—) Q-34
Calder Cr.	Alas. WR93	(8) N-16
Caldera Cr.	Alas. WC29	(—) N-17
California Cr.	Wash.	(—) Q-24
Calvert Cr.	Alas. 661	(—) J-12
Camas Cr.	Idaho	(—) S-28
Camp Cr. (Iliamna Lake)	Alas.	(—) I-13
Camp Cr.	Oreg.	(—) Q-28
Camp Cr.	Oreg.	(—) R-28
Campbell Cr.	Alas.	(16B) J-11
Campbell Cr.	Alas. 299	(15*) K-12
Camp Taylor Cr.	Alas. WC57[4]	(8) N-16
Canine Cr.	Alas. K9	(7) O-18
Caniro Lake (Attu I.)	Alas.	(25) A-20
Cannery Cr.	Alas. 241	(—) K-11
Cannery Cr.	Alas.	(—) N-14
Cannery Cr.	Alas. K152	(—) N-17
Cannery Cr.	Alas. K7	(—) O-18
Cannery Bay Cr. (Unalaska I.)	Alas.	(25) F-19
Cannery Station Cr.	Alas. 78K	(18) I-15
Canning Cr.	Alas.	(—) K-2-3
Canoe Cr.	Alas. 850	(—) K-12
Canoe Riv.	Alas. 27	(19) G-17
Canyon Cr.	Alas.	(—) F-7-8
Canyon Cr. (Iliamna Lake)	Alas.	(—) I-13
Canyon Cr. (Karluk Lake)	Alas.	(—) I-15
Canyon Cr.	Alas.	(16B) J-12

[3] Shown as "Boundry" on map.

[4] Shown as "WR57" on map.

Continued ...

Appendix I. Continued.

Name	State	Location
Canyon Cr.	Alas. 279	(—)K-12
Canyon Cr.	Wash.	(—)Q-24
Canyon Lake	Alas.	(20)G-13
Captain Cr.	Alas. 827	(—)K-12
Car Cr. (Iliamna Lake)	Alas.	(20)I-13
Carbon Cr.	Alas.	(23*)H-3
Carbon Cr.	Alas.	(16B)J-11
Carbon Riv.	Wash.	(—)Q-25
Caribou Cr.	Alas.	(16B)K-11
Caribou Riv. and tributaries	Alas.	(19)G-17
Carlana Cr.	Alas. K90A	(—)O-17
Carlsen Cr.	Alas. 54	(—)K-12
Carmel Cr. (Kodiak)	Alas.	(—)I-15
Carmel Riv.	Calif.	(—)Q-36
Carmen Lake and streams	Alas.	(—)J-12
Carp Cr.	Alas. K30	(—)O-17
Carpenter Cr.	Alas.	(16B)J-11
Carr Cr.	Alas. 766	(—)K-12
Carroll Riv.	Alas. K99	(7)O-17
Carter Cr.	Alas.	(—)J-12
Cascade Cr. (Karluk Lake)	Alas.	(—)I-15
Cascade Cr.	Alas. E7C	(10)N-15
Cascade Cr.	Wash.	(—)Q-25
Cascade Riv.	Alas. 285	(15*)K-12
Castle Cr.	Oreg.	(—)Q-30
Castle Riv.	Alas. WR61	(10)N-16
Cat Cr. (Brooks Lake)	Alas.	(—)H-14
Catching Cr.	Oreg.	(—)P-Q-29
Cateract Cr.	Alas. 49	(—)K-12
Cathead Cr.	Alas. 699	(—)K-12
Cathedral Riv.	Alas.	(19)G-17
Cathedral Falls Cr.	Alas. E33	(10)N-16
Catherine Cr.	Oreg.	(6)R-27
Cedar Cr.	Alas. 299a	(—)K-12
Cedar Cr.	Oreg.	(—)Q-27
Cedar Cr.	Oreg.	(—)Q-27
Cedar Cr.	Wash.	(—)Q-25
Cedar Cr.	Wash.	(—)Q-26
Cedar Cr.	Wash.	(—)Q-26
Cedar Cr.	Wash.	(—)Q-27
Cedar Cr.	Wash.	(—)Q-27
Cedar Riv.	Wash.	(3)Q-25
Chakachamna Lake	Alas.	(16C)I-11
Chakachatna Riv.	Alas.	(16C)I-J-11
Chakina Riv.	Alas.	(—)L-11
Chakok Riv.	Alas.	(16A)J-13
Chalmers Riv.	Alas. 741	(15*)K-12
Chambers Cr.	Wash.	(—)Q-25
Chandalar Riv.	Alas.	(22)K-4-5-6
Chandler Riv.	Alas.	(23*)J-3
Charlene Cr. (Naknek Lake)	Alas.	(—)I-14
Charley Riv.	Alas.	(22)L-7
Charlies Cr.	Wash.	(—)Q-26
Chase Riv.	Alas. 23	(—)K-12
Chatanika Riv.	Alas.	(22)J-K-7
Chauekuktuli Lake	Alas.	(20)H-12
Checats Cr.	Alas. K38	(7)O-18
Chehalis Riv.	Wash.	(3)Q-26
Chekok Cr. (Iliamna Lake)	Alas.	(—)I-13
Chelatna Lake	Alas.	(17)J-10
Chena Riv.	Alas.	(22)K-8
Chenega Cr.	Alas. 628	(—)J-12
Chenik Cr. and Lake	Alas.	(16C)I-13
Cherry Cr.	Oreg.	(—)Q-29
Chetco Riv.	Oreg.	(—)P-30
Chewak Riv.	Wash.	(4)Q-24
Chew's Cr. (Naknek Lake)	Alas.	(—)H-14
Chichagof Bay creeks	Alas.	(—)G-17
Chichantna Riv.	Alas.	(—)J-11
Chickaloon Riv.	Alas.	(16B)J-11
Chickaloon Riv.	Alas.	(16B)J-12
Chickamin Riv.	Alas. K44	(7)0-17
Chickeman Cr.	Wash.	(—)Q-25
Chicken Cr.	Alas. 675	(—)K-12
Chicken Cr.	Alas. I14A	(11)N-14
Chicken Cr.	Oreg.	(—)R-28
Chickitnak Riv.	Alas.	(—)H-12
Chico Cr.	Calif.	(1)Q-33
Chignik Lake and Riv.	Alas.	(19)H-16
Chikuminuk Lake	Alas.	(20)H-12
Chilchitna Riv.	Alas.	(—)H-12
Chilcoot Cr.	Oreg.	(—)Q-29
Chilikadrontna Riv.	Alas.	(20)I-12
Chilkat Riv.	Alas. W1	(13)N-13
Chilkoot Riv.	Alas. W2	(13)N-13
Chilligan Riv.	Alas.	(16C)I-11
Chimevisky Lagoon	Alas. 495	(15*)J-12
China Cr.	Oreg.	(—)P-29
Chinkelyes Cr. (Iliamna Lake)	Alas.	(—)I-13
Chiroskey Riv.	Alas.	(21)G-9
Chistochina Riv.	Alas.	(15)K-10
Chitanana Riv.	Alas.	(22)I-J-8
Chitina[5] Riv.	Alas.	(15)K-L-11
Chiwaukan Cr.	Wash.	(—)Q-25
Chiwawa Riv.	Wash.	(5)Q-25
Chokotonk Riv.	Alas.	(20)I-12
Chowchilla Riv.	Calif.	(—)Q-35
Chuck Riv.	Alas. E3	(10)N-15
Chuckanut Cr.	Wash.	(—)Q-24
Chuilnak Riv.	Alas.	(21)G-10-11
Chuit Riv.	Alas.	(16B)J-11
Chulitna Riv. (Lake Clark)	Alas.	(—)I-12
Chulitna Riv.	Alas.	(—)J-10

[5] Shown as "Chitna" on map.

Continued ...

Appendix I. Continued.

Name	State	Location
Chunilna Cr.	Alas.	(—) J-10
Cinder Riv.	Alas.	(18) H-15
Cinder Riv.	Alas.	(—) I-13
Cispus Riv.	Wash.	(—) Q-26
Clackamas Riv.	Oreg.	(4) Q-27
Clallam Cr.	Wash.	(—) P-24
Clam Cr.	Alas. WC7	(—) N-17
Clam Beach Cr.	Alas. 703	(—) K-13
Clamdigger's Cr.	Alas. 862	(—) K-12
Clark Bay creeks	Alas.	(—) G-17
Clark Cr.	Oreg.	(—) R-28
Clark Lake	Alas.	(20) I-12
Clatskanie Riv.	Oreg.	(4) Q-26-27
Claw Cr.	Alas. 632	(—) J-12
Claw Peak Cr.	Alas.	(—) J-12
Clear Cr.	Alas.	(15) K-L-12
Clear Cr.	Alas. K48–	(—) O-17
Clear Cr.	Calif.	(1) Q-31
Clear Cr.	Oreg.	(—) Q-27
Clear Cr.	Oreg.	(—) Q-27
Clear Cr.	Wash.	(—) Q-24
Clear Riv.	Alas. W41	(9) N-15
Clearwater Cr.	Alas. K44-5	(—) 0-17
Clearwater Cr.	Wash.	(—) Q-24
Clearwater Riv., and North, Middle, and South Forks	Idaho-Wash.	(3, 6) P-Q-25, R-S-26, S-27
Cle Elum Riv.	Wash.	(—) Q-25
Clemence Cr.	Alas. 516	(—) J-12
Cleo Cr. (Becharof Lake)	Alas.	(—) I-15
Cliff House Cr.	Alas.	(16A) J-12
Clock Cr.	Alas. 297	(—) K-12
Cloquallum Riv.	Wash.	(—) Q-26
Cloudman Cr.	Alas. 111	(—) K-12
Clover Cr.	Alas. K157	(—) N-17
Coal Cr. (Herendeen Bay)	Alas.	(19) G-17
Coal Cr.	Alas.	(16B) J-11
Coal Cr.	Oreg.	(—) P-30
Coal Cr.	Oreg.	(—) Q-27
Coal Cr.	Wash.	(—) Q-26
Coal Cr. Lake	Alas.	(16B) J-11
Cobb Cr.	Alas. K22–2	(—) O-17
Cochrane Cr.	Alas. 461	(—) J-12
Coco Cr.	Alas. WC24	(8) N-17
Coffee Cr.	Alas.	(—) J-10
Coffman Cr.	Alas. WR108	(8) N-17
Coghill Lake and Riv.	Alas. 322	(—) K-11
Coho Cr.	Alas. 65	(15*) K-12
Coho Cr.	Alas. K44–1	(—) O-17
Colawah Riv., and North and South Forks	Wash.	(—) P-25
Coleen Riv.	Alas.	(22) L-5
Coleman Cr. (Balboa Bay)	Alas.	(19) G-17

Name	State	Location
Coleman Riv.	Alas.	(—) L-5
Collawash Riv.	Oreg.	(—) Q-27
Columbia Cr.	Alas. 205	(15*) K-12
Columbia Riv. (mouth)	Oreg.-Wash.	(4) Q-26
Colville Lake and creeks	Alas.	(18) I-14
Colville Riv. (mouth)	Alas.	(23*) J-2
Comfort Cr.	Alas. 46	(—) K-12
Comstock Cr.	Alas. 504	(—) J-12
Confusion Cr.	Alas. 130	(15*) K-11
Constant Lake	Alas.	(—) C-21
Constantine Cr.	Alas. 815	(15*) K-12
Control Cr.	Alas. 52	(—) K-12
Cook Cr.	Alas. 828	(—) K-12
Cooper Cr. and Lake	Alas.	(16A) J-12
Coos Riv., and West Fork	Oreg.	(2) P-Q-29
Copalis Riv.	Wash.	(3) P-25
Copper Cr. and Lake	Alas.	(15) L-10
Copper Cr.	Alas. WC13	(—) N-17
Copper Riv. (Iliamna Lake)	Alas.	(20) I-13
Copper Riv.	Alas.	(15) K-10-11-12, L-10
Coquille Riv., and East, Middle, North and South Forks	Oreg.	(2) P-Q-29-30
Cories Lake (Attu I.)	Alas.	(25) A-20
Cork's Cr.	Alas.	(—) N-16
Cosna Riv.	Alas.	(22) J-8
Cosumnes Riv.	Calif.	(1) Q-34
Cottonwood Cr. (Karluk Lake)	Alas.	(—) I-15
Cottonwood Cr. and Lake	Alas.	(16B) J-11
Cottonwood Cr.	Calif.	(1) Q-32
Cottonwood Cr.	Idaho	(—) R-S-26
Countess Cr.	Alas. 637	(—) J-12
Cove Cr.	Alas. 442	(—) J-12
Covington Cr.	Wash.	(—) Q-25
Cow Cr.	Alas. K79	(7) O-17
Cow Cr.	Calif.	(1) Q-32
Cow Cr.	Oreg.	(2) Q-30
Cowee Riv.	Alas.	(12) N-14
Coweman Riv.	Wash.	(4) Q-26
Cowlitz Riv.	Wash.	(4) Q-26
Cow Pen Cr.	Alas. 242	(—) K-11
Crab Cr.	Alas. K111	(7) O-17
Crabtree Cr.	Oreg.	(4) Q-28
Craig Cr.	Calif.	(—) Q-31
Cranberry Cr.	Alas.	(—) H-13
Cranberry Cr.	Wash.	(—) Q-25
Crater Lake Cr.	Alas. 9	(—) K-12
Crescent Cr.	Alas.	(—) J-12
Crescent Riv.	Alas. 318	(—) K-11
Cripple Cr.	Alas.	(—) F-8
Cripple Cr.	Alas.	(—) J-10

Continued. ...

Appendix I. Continued.

Name	State	Location
Crittenden Cr.	Alas. WR4	(7)N-16
Crooked Cr.	Alas.	(22)K-7
Crooked Cr.	Alas.	(—)J-12
Crooked Cr. (Ugashik Lake)	Alas.	(—)H-15
Crooked Cr.	Alas. 145	(15*)K-11
Crooked Cr.	Idaho	(—)S-27
Crooked Riv.	Oreg.	(4)Q-28
Culross Cr.	Alas. 479	(—)J-12
Curran Cr.	Alas. 760	(15*)K-12
Currant Cr. (Lake Clark)	Alas.	(—)I-12
Cutler Riv.	Alas.	(23)H-5
Cutthroat Cr.	Alas. 95	(—)K-12
Dago Cr.	Alas.	(18)H-15
Dago Frank's Cr.	Alas.	(—)H-16
Dairy Cr.	Oreg.	(4)Q-27
Dakavak Cr.	Alas. 119K	(18)I-14
Dakli Riv.	Alas.	(—)H-6-7
Dakota Cr.	Wash.	(—)Q-24
Dall Cr.	Alas. K117B	(7)O-17
Dall Riv.	Alas.	(22)J-6
Danger Cr.	Alas. 10K	(18)I-14
Dangerous Riv.	Alas.	(14)M-13
Dan's Cr.	Alas. 836	(—)K-12
Daves Cr.	Alas.	(16A)J-12
Davies Riv.	Alas.	(12)N-14
Davis Riv.	Alas.	(7)O-17
Day Cr.	Wash.	(—)Q-24
Dayville Cr.	Alas. 134	(—)K-11
Deadman Cr.	Calif.	(—)Q-31
Deadman Riv.	Alas. 74K	(18)I-15
Deep Cr.	Alas.	(16A)J-12-13
Deep Cr.	Alas. 865	(—)K-12
Deep Cr.	Alas. E47[6]	(9)N-16
Deep Water Cr.	Alas. 491	(—)J-12
Deer Cr. (Ugashik Lake)	Alas.	(—)H-15
Deer Cr.	Alas. 817	(—)K-12
Deer Cr.	Alas. WC16	(—)N-17
Deer Cr.	Calif.	(—)Q-31
Deer Cr.	Calif.	(1)Q-32-33
Deer Cr.	Idaho	(—)S-27
Deer Cr.	Oreg.	(—)R-28
Deer Cr., and North Fork	Wash.	(—)Q-24-25
Deer Valley Cr. (Herendeen Bay)	Alas.	(19)G-17
Delarof Harbor Cr.	Alas.	(—)G-17
Delight Cr.	Alas.	(16A)J-13
Delta Cr.	Alas.	(22)K-8-9
Delta Riv.	Alas.	(22)K-8-9
Dement Cr.	Oreg.	(—)P-30
Dennis Cr. (Iliamna Lake)	Alas.	(—)I-13
Derickson Cr.	Alas. 289	(—)K-12
Derilict Cr.	Alas. 871	(—)K-12
Deschutes Riv.	Oreg.	(4)Q-27-28
Deschutes Riv.	Wash.	(3)Q-25-26
Deshka Lake and Riv.	Alas.	(17)J-10-11
Des Moines Cr. (Wide Bay)	Alas.	(18)H-15
Devilfish Cr.	Alas. WC66	(8)N-16
Devils Cr.	Alas.	(—)J-12
Dick Cr.	Alas.	(15)K-12
Dickeman Cr.	Alas.	(—)N-17
Dickey Lake and Riv.	Wash.	(—)P-24-25
Dicky Lake	Alas.	(15)K-10
Dillon Beach Cr.	Calif.	(—)Q-34
Dirty Cr. (Naknek Lake)	Alas.	(—)I-14
Disappearance Cr.	Alas. K150	(8)N-17
Discher Cr.	Alas. 502	(—)J-12
Dishna Riv.	Alas.	(21)H-9-10
Dixie Cr.	Oreg.	(—)R-28
Dog Bay Cr.	Alas. 41K	(18)I-15
Dog Salmon Cr.	Alas. 77K	(18)I-15
Dog Salmon Cr.	Alas. 806	(—)K-12
Dog Salmon Cr.	Alas. WC40	(8)N-17
Dog Salmon Cr.	Alas. K167	(—)N-17
Dog Salmon Riv.	Alas.	(18)H-15
Dog Salmon Riv.	Alas.	(—)I-16
Dohn Cr.	Alas.	(14)M-13
Donaldson Cr.	Alas. 120	(—)K-12
Dolomi Cr.	Alas. K139	(8)N-17
Dora Cr.	Alas. K148	(—)N-17
Dosewallips Riv.	Wash.	(3)Q-25
Double Cr.	Alas. 831	(—)K-12
Doubtful Cr.	Alas. 651	(—)J-12
Douglas Cr.	Alas.	(16C)I-13
Drano Lake	Wash.	(—)Q-27
Dream Cr. (Gibraltar Lake)	Alas.	(—)I-13
Drift Riv.	Alas.	(16C)I-12
Dry Cr.	Alas.	(—)H-16
Dry Cr.	Alas. 754	(—)K-12
Dry Cr.	Oreg.	(—)P-30
Dryden Cr.	Oreg.	(—)Q-30
Dubli Riv.	Alas.	(—)H-7
Duck Riv.	Alas. 116	(—)K-12
Duckabush Riv.	Wash.	(3)Q-25
Dudidonto Riv.	Alas.	(—)O-14
Dumpling Cr. (Nos. 1-4) (Naknek Lake)	Alas.	(—)I-14
Duncan Cr. and Lake	Alas.	(—)J-10
Duncan Cr.	Alas. WR58	(10)N-16
Dundas Riv.	Alas.	(13)M-14
Dungeness Riv.	Wash.	(3)Q-24-25
Dunuletak Cr.	Alas.	(16C)I-13
Durkee Cr.	Alas.	(28)K-12
Durkee Cr.	Oreg.	(—)R-28
Duwamish Riv.	Wash.	(—)Q-25
" E " Cr. (Ugashik Lake)	Alas.	(—)H-15

Continued ...

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[6] Shown as " 47 " on map.

APPENDIX I. Continued.

Name	State	Location
Eagle Cr.	Alas. 825	(15*) K-12
Eagle Cr.	Alas. WR109	(8) N-17
Eagle Cr.	Calif.	(—) Q-33
Eagle Cr.	Oreg.	(4) Q-27
Eagle Cr.	Oreg.	(—) Q-27
Eagle Cr.	Oreg.	(6) R-28
Eagle Riv.	Alas.	(16B) J-11
Eagle Riv.	Alas.	(12) N-14
Eagle Riv.	Alas. WR13	(7) O-16
Eagle Bay Cr., NE. and NW. (Iliamna Lake)	Alas.	(20) I-13
Eagle Harbor Cr.	Alas. 31K	(18) I-15
Eaglek Riv.	Alas. 281	(—) K-12
Earn Riv.	Alas.	(—) N-10
East Riv.	Alas.	(—) M-13
East Finger Cr.	Alas. 484	(—) J-12
East LaGorce Cr. (Naknek Lake)	Alas.	(—) I-14
East Twin Cr.	Alas. 294	(15*) K-12
Eaton Cr.	Alas. W12A	(—) N-15
Eccles Cr.	Alas. 5	(—) K-12
Edna Cr.	Alas. WC74	(—) N-17
Eek Riv.	Alas.	(20) G-12
Eek Lake Cr.	Alas. WC17	(8) N-17
Eel Riv., and East, Middle, North and South Forks	Calif.	(1) P-Q-32-33
Egavik Riv.	Alas.	(21) G-8
Egegik Riv. (Egegik Bay)	Alas.	(18) H-14
Eickelberg Cr.	Alas. 221	(—) K-12
Eklutna Cr. and Lake	Alas.	(16B) J-11
Elbow Cr.	Alas. 105K	(18) I-15
El Capitan Cr.	Alas. WC60	(—) N-16
Eleshansky Cr.	Alas. 510	(—) J-12
Elk Cr.	Calif.	(1) Q-33
Elk Cr.	Idaho	(—) R-26
Elk Cr.	Oreg.	(—) P-29
Elk Cr.	Oreg.	(2) Q-27
Elk Cr.	Oreg.	(—) Q-27
Elk Cr.	Oreg.	(—) Q-29
Elk Cr.	Oreg.	(—) Q-30
Elk Cr.	Wash.	(—) Q-26
Elk Riv.	Oreg.	(2) P-30
Elkhorn Cr.	Wash.	(—) Q-26
Elkhorn Riv.	Wash.	(—) Q-26
Ella Cr.	Alas. K72	(7) O-18
Elliott Cr.	Oreg.	(—) Q-27
Elokomin Riv.	Wash.	(3, 4) Q-26
Elwha Riv.	Wash.	(3) Q-24-25
Emerald Cr.	Alas. 201	(—) K-12
Emerald Cr.	Alas. WR20	(7) N-17
English Cr.	Alas. 803	(—) K-12
English Cr.	Calif.	(—) Q-31
English Bay Cr. and Lakes	Alas.	(16A) J-13
Ennis Cr.	Wash.	(—) Q-24
Entiat Riv.	Wash.	(5) Q-24-25
Entry Cove Cr.	Alas. 434	(—) J-12
Epizetka Riv.	Alas.	(23*) G-3
Erb Cr.	Alas. 604	(—) J-12
Eshamy Riv.	Alas. 511	(—) J-12
Esker Cr.	Alas.	(—) M-13
Esther Riv.	Alas. 336	(—) J-12
Estrella Cr.	Alas. WC28	(—) N-17
Etches Cr.	Alas. 811	(—) K-12
Etivluk Riv.	Alas.	(23*) H-4
Etna Cr.	Calif.	(—) Q-31
Euchre Cr.	Oreg.	(—) P-30
Eulachon Cr.	Alas. K48-1	(7) O-16
Evans Cr.	Alas. 664	(—) K-12
Evans Cr.	Oreg.	(—) Q-30
Evans Cr.	Wash.	(—) Q-26
Ewan Cr.	Alas. 603	(—) J-12
"F" Cr. (Ugashik Lake)	Alas.	(—) H-15
FAA Cr.	Alas. 870	(15*) K-12
Fall Cr.	Alas.	(—) J-K-12
Fall Cr.	Alas. 673	(—) K-12
Fall Cr.	Alas. WR55	(10) N-16
Fall Cr.	Oreg.	(4) Q-29
Fall Cr.	Wash.	(—) Q-26
Fall Riv.	Wash.	(3) Q-26
Falls Cr. (Karluk Lake)	Alas.	(—) I-15
Falls Cr.	Alas.	(—) N-16
False Cr. (Iliamna Lake)	Alas.	(—) I-13
Farragut Riv.	Alas. E7	(10) N-15
Fawcett Cr.	Oreg.	(—) Q-27
Feather Riv.	Alas.	(—) F-8
Feather Riv., and South, Middle and North Forks	Calif.	(1) Q-33-34
Featherly Cr. (Becharof Lake)	Alas.	(—) H-15
Ferebee Riv.	Alas.	(13) N-13
Fidalgo Riv.	Alas. 86	(—) K-12
Fillmore Riv.	Alas. K8	(7) O-18
Finch Cr.	Wash.	(—) Q-25
Fingerling Cr. (Naknek Lake)	Alas.	(—) H-14
Finney Cr.	Wash.	(—) Q-24
Finski Cr.	Alas. 298	(15*) K-12
Fish Cr.	Alas.	(22) J-6
Fish Cr. and Lake	Alas.	(—) J-10
Fish Cr.	Alas.	(16B) J-11
Fish Cr.	Alas.	(16B, 17) J-11
Fish Cr.	Alas.	(16A) J-13
Fish Cr.	Alas.	(15) K-9
Fish Cr.	Alas. 89	(—) K-12
Fish Cr.	Alas. E9C	(12) N-14
Fish Cr.	Alas. E10G	(12) N-14
Fish Cr.	Alas. K1-1	(—) O-17
Fish Cr.	Alas. K103	(—) O-17

Continued …

Appendix I. Continued.

Name	State	Location
Fish Cr.	Calif.	(—)Q-31
Fish Lake	Alas.	(—)K-9
Fish Riv.	Alas.	(—)G-7-8
Fisher Cr.	Oreg.	(—)Q-28
Fishery Cr.	Alas. W48	(11)N-15
Fishery Cr.	Calif.	(—)Q-31
Fishtrap Cr.	Wash.	(—)Q-24
Fitz Cr.	Alas.	(16C)I-13
Fitzgibbon Cr.	Alas. K46A	(—)O-17
Fivemile Cr.	Alas. E31D	(—)N-15
Flannigan Cr.	Alas.	(—)N-14
Flat Cr.	Alas. K11A	(—)O-18
Fleming Cr.	Alas. 8	(—)K-12
Fletcher Cr.	Alas. 225	(—)K-12
Flicker Cr.	Alas. WR96	(—)N-16
Floras Cr.	Oreg.	(—)P-30
Fools Cr.	Alas. WR25	(7)N-16
Forks Cr.	Wash.	(—)Q-26
Fort Jones Cr.	Calif.	(—)Q-31
Fortymile Riv.	Alas.	(22)L-8
Fox Cr.	Alas.	(16A)J-13
Fox Cr.	Alas. 110	(—)K-12
Fox Cr.	Oreg.	(—)Q-27
Fox Riv.	Alas.	(16A)J-13
Fracture Cr.	Alas.	(19)H-16
Frank's Cr. (Becharof Lake)	Alas.	(—)H-15
Frank's Cr.	Alas. WR8	(7)O-16
Frank's Lagoon	Alas.	(—)G-16
Frazer Lake (Kodiak)	Alas.	(—)I-15
Frederick Cr.	Alas. K133	(—)N-17
French Cr.	Wash.	(—)Q-24-25
French Pete Cr.	Oreg.	(—)Q-28
Friday Cr.	Alas.	(16B)J-11
Friday Cr.	Wash.	(—)Q-24
Fritz Cr.	Alas.	(—)J-13
Frosty Cr.	Alas.	(—)G-17
Frosty Cr.	Alas. WR16	(—)N-16
Funnel Cr.	Alas.	(—)I-13
Funny Riv.	Alas.	(—)J-12
Gable Cr.	Wash.	(—)Q-26
Gakona Riv.	Alas.	(15)K-10
Gales Cr.	Oreg.	(—)Q-27
Game Cr.	Alas. I16	(11)N-14
Garcia Riv.	Calif.	(1)Q-34
Garden Cr.	Alas. 810	(15*)K-12
Garwood Cr.	Wash.	(—)Q-26
Gate Cr.	Oreg.	(—)Q-28
Gazos Cr.	Calif.	(—)Q-35
Gechiak Cr. and Lake	Alas.	(—)G-13
George Cr.	Alas.	(—)A-20
Germany Cr.	Wash.	(—)Q-26
Gerstle Riv.	Alas.	(22)K-8-9
Gibbon Cr.	Alas. 789	(15*)K-12
Gibbon Cr.	Wash.	(—)Q-26
Gibraltar Cr. and Lake	Alas.	(20)I-13
Gilbert Cr.	Alas. 464	(—)J-12
Gilmour Cr.	Alas. 148	(—)K-11
Gines Cr.	Alas.	(14)M-13
Gisasa Riv.	Alas.	(21)H-7
Glacial Riv.	Alas. W41A	(9)N-15
Glacier Cr.	Wash.	(—)Q-24
Glacier Riv.	Alas.	(—)J-12
Gladhough Cr.	Alas. 106	(—)K-12
Gladys Riv.	Alas.	(—)N-13
Glenlyon Riv.	Alas.	(—)N-10
Goat Cr.	Alas.	(—)L-10
Gold Cr.	Alas.	(—)J-10
Gold Cr.	Alas. 149	(—)K-11
Golden Lagoon	Alas. 310	(15*)J-K-12
Golden Riv.	Alas. 311	(—)K-12
Goldsborough Cr.	Wash.	(—)Q-25
Goldstream Cr.	Alas.	(22)J-8
Goodnews Lake	Alas.	(20)G-13
Goodnews Riv.	Alas.	(20)G-13
Goodpaster Riv.	Alas.	(22)K-8
Goose Cr.	Calif.	(1)Q-31
Grace Cr.	Alas. WC21	(8)N-18
Grace Cr. and Lake	Alas. K75	(7)O-17
Grande Ronde[7] Riv.	Oreg.	(6)R-27
Grandy Cr.	Wash.	(—)Q-24
Granite Cr. (Iliamna Lake)	Alas.	(20)I-13
Granite Cr.	Alas.	(16B)J-11
Granite Cr.	Alas. 227	(—)K-12
Granite Cr.	Alas. I15	(11)N-14
Granite Cr.	Alas. W25	(11)N-15
Granite Cr.	Alas.	(7)O-17
Grant Cr. and Lake	Alas.	(16A)J-12
Grant Cr.	Alas. K49	(7)O-16
Grant Riv. (Wood Riv.)	Alas.	(—)H-13
Grass Cr. (Herendeen Bay)	Alas.	(19)G-17
Grassy Point Cr. (Karluk Lake)	Alas.	(—)I-15
Grave Cr.	Oreg.	(—)Q-30
Gravel Cr.	Alas.	(16B)K-11
Gravelly Cr.	Alas. K184-1	(—)N-17
Graveyard Cr.	Alas. 756	(—)K-12
Gravina Riv.	Alas. 50	(15*)K-12
Gravina Point Cr.	Alas. 40	(15*)K-12
Grayling Cr.	Alas.	(—)K-11
Grays Riv.	Wash.	(3, 4)Q-26
Grecian Lake and Riv.	Alas.	(16C)I-12
Green Cr.	Alas. 788	(15*)K-12
Green Riv.	Wash.	(3)Q-25
Green Riv.	Wash.	(4)Q-26
Greenhorn Cr.	Wash.	(—)Q-26
Greens Cr.	Alas. W44	(11)N-14
Greenview Cr.	Calif.	(—)Q-31

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[7] Shown as "Grand Ponde" on map.

Continued

APPENDIX I. Continued.

Name	State	Location
Greenwater Riv.	Wash.	(—)Q-25
Gregorioff Cr.	Alas. 123	(—)K-11
Gretchen Cr. (Afognak I.)	Alas.	(—)I-14
Greystone Cr.	Alas. 490	(15*)J-12
Griffin Cr.	Wash.	(—)Q-25
Grindle Cr. (Egegik system)	Alas.	(—)H-I-15
Grosvenor Cr. (Nos. 1-9)	Alas.	(—)I-14
Grosvenor Lake	Alas.	(18)I-14
Grosvenor Riv.	Alas.	(—)I-14
Gualala Riv.	Calif.	(1)Q-34
Gulkana Lake and Riv.	Alas.	(15)K-10
Gull Point Cr.	Alas. 30K	(18)I-15
Gumboot Cr.	Alas. 507	(—)J-12
Gun Cr.	Alas.	(15)K-9
Hackett Riv.	Alas.	(—)N-14
Hadweenzic Riv.	Alas.	(22)K-6
Halferty Cr.	Alas. 454	(—)J-12
Halfway Cr.	Alas.	(—)I-15
Halibut Cr.	Alas. K4	(7)O-17
Halibut Bay Cr.	Alas. 85K	(18)I-15
Halleck Riv.	Alas. K2	(7)O-17
Hallo Cr.	Alas. 112K	(18)I-14
Halverson Cr.	Alas. 656	(—)J-12
Hamilton Cr.	Alas. E33A	(10)N-16
Hamilton Cr.	Wash.	(—)Q-27
Hamma-Hamma Riv.	Wash.	(3)Q-25
Hana Cr.	Alas. 505	(15*)J-12
Hanaford Cr.	Wash.	(—)Q-26
Hanley Cr.	Alas. 489	(—)J-12
Hanna Lake	Alas.	(15)L-12
Hanning Cr.	Alas. 710	(15*)K-13
Hansen Cr.	Wash.	(—)Q-24
Hansen's Cr.	Alas.	(—)G-18
Happy Cr.	Calif.	(—)Q-31
Harding Riv.	Alas. WR10	(7)O-16
Hardscrabble Cr. (Grosvenor Lake)	Alas.	(—)I-14
Hardsen Cr. and Lake	Alas.	(—)I-14
Hardy Cr.	Alas. 834	(—)K-12
Harlequin Lake	Alas.	(14)M-13
Harley Cr.	Alas. W6A	(—)N-15
Harris Cr.	Alas.	(20)H-12-13
Harris Riv.	Alas. K176	(8)N-17
Harrison Cr.	Alas. 414	(—)J-12
Harry Cr.	Alas. K16	(7)O-18
Hartney Cr.	Alas. 2	(—)K-12
Harvey Cr.	Alas.	(—)N-10
Hasselborg Cr.	Alas. W52	(11)N-15
Hatchery Cr.	Alas. K54-1	(7)O-16-17
Hatlet Riv.	Alas.	(—)K-11
Hawk Riv.	Alas.	(21)G-10
Hawkins Cr.	Alas. 847	(—)K-12
Hayden Cr.	Alas. 677	(—)K-12
Hayden Cr.	Idaho	(—)S-28

Name	State	Location
Hayes Cr.	Oreg.	(—)P-30
Hayes Riv.	Alas.	(—)I-J-11
Hayes Riv.	Alas.	(—)N-O-13
Hayfork Riv.	Calif.	(1)Q-32
Headwater Cr. (Brooks Lake)	Alas.	(—)H-14
Healy Riv.	Alas.	(22)K-8
Heckman Cr.	Alas. K55D	(—)O-17
Helm Cr.	Alas. K58	(—)O-17
Heney Cr.	Alas. 4	(—)K-12
Henry Cr.	Calif.	(—)Q-35
Herman Cr.	Alas. K50	(—)O-16-17
Herman Cr.	Oreg.	(—)Q-27
Herring Cr.	Alas. 692	(—)K-12
Herring Cr.	Alas. K92	(—)O-17
Hess Cr.	Alas.	(22)J-7
Hessa Cr.	Alas. WC1	(—)N-18
Hetta Lake Cr.	Alas. WC12	(—)N-17
Hewitt Lake	Alas.	(17)J-11
Hicks Cr.	Alas.	(16B)K-11
Hidden Cr. (Naknek Lake)	Alas.	(—)H-14
Hidden Cr. (Brooks Lake)	Alas.	(—)I-14
Hidden Cr.	Alas.	(—)J-12
Hidden Cr.	Alas. 18	(—)K-12
Hidden Cr.	Alas.	(12)N-14
Hidden Cr.	Alas. K6	(7)O-17
Hidden Lake	Alas.	(16A)J-12
Hidden Basin Cr.	Alas. 27K	(18)I-15
High Cr. (Cinder Riv.)	Alas.	(—)I-13
High Falls Cr.	Alas.	(—)K-12
Hilda Cr.	Alas. E9B	(12)N-14
Himes Cr.	Wash.	(—)Q-25
Hobo Cr.	Alas. 417	(—)J-12
Hodanza Riv.	Alas.	(22)J-K-6
Hoffstadt Cr.	Wash.	(—)Q-26
Hogan Cr.	Alas. 681	(—)K-12
Hogatza Riv.	Alas.	(21)I-6
Hogg Cr.	Alas. 653	(—)J-12
Hoh Riv., and South Fork	Wash.	(3)P-Q-25
Hoholitna Riv.	Alas.	(20*)H-11
Hoko Riv.	Wash.	(3)P-24
Holbrook Cr.	Alas. WC70	(8)N-16
Holitna Riv.	Alas.	(20*)H-11
Holyoke Cr.	Alas. 327	(—)K-11
Hood Riv.	Oreg.	(4)Q-27
Hoodoo Lake	Alas.	(19)G-17
Hoquiam Riv.	Wash.	(—)Q-26
Hornbrook Cr.	Calif.	(—)Q-31
Horse Cr.	Oreg.	(—)Q-28
Horse Marine Cr.	Alas. 76K	(18)I-15
Horseshoe Cr.	Alas. 676	(—)K-12
Hourglass Lake	Alas.	(—)J-10
House Cr.	Oreg.	(—)P-30

Continued ...

Appendix I. Continued.

Name	State	Location
Hubbard Cr.	Alas. I25	(11) N-14
Hummer Cr.	Alas. 425	(15*) J-12
Humpback Cr.	Alas. I19	(11) N-14
Humpback Cr.	Alas. K21	(—) O-17
Humpie Cr.	Alas.	(—) N-15
Humptulips Riv.	Wash.	(3) Q-25
Humpy Cr.	Alas. 66K	(18) I-16
Humpy Cr.	Alas. 11	(—) K-12
Humpy Cr.	Alas. I10	(11) M-14
Humpy Cr.	Alas. K44-3	(—) O-17
Hunt Riv.	Alas.	(23) H-5
Hunter Cr.	Alas. WC2	(—) N-18
Hunters Cr.	Oreg.	(—) P-30
Hurtle Cr.	Alas.	(—) K-11
Huslia Riv.	Alas.	(21) H-7
Hutchinson Cr.	Wash.	(—) Q-24
Hydaburg Cr.	Alas. WC18	(8) N-17
Hyde Cr.	Alas. 866	(—) K-12
Icicle Cr.	Wash.	(5) Q-25
Iditarod Riv.	Alas.	(21) H-9-10
Igushik Riv.	Alas.	(20) H-13-14
Ikpikpuk Riv.	Alas.	(23*) I-2
Iliamna Lake and Riv.	Alas.	(20) I-13
Iliuk Cr. (Nos. 1–3) (Naknek Lake)	Alas.	(—) I-14
Illinois Riv.	Oreg.	(2) P-Q-30
Ilnik Cr.	Alas.	(—) H-16
Imnachuk Riv.	Alas.	(23) G-6-7
Imnaha Riv.	Oreg.	(6) R-27
Inaru Lake and Riv.	Alas.	(23*) H-1-2
Indecision Cr. (Mother Goose Lake)	Alas.	(—) H-15
Indian Cr.	Alas.	(16B) J-11-12
Indian Cr.	Alas.	(16A) J-12
Indian Cr.	Alas.	(—) K-10
Indian Cr.	Alas. 117	(—) K-12
Indian Cr.	Alas. W12	(—) N-15
Indian Cr.	Alas. K176-1	(—) N-17
Indian Cr.	Alas. K78	(—) O-17
Indian Cr.	Oreg.	(—) S-28
Indian Riv.	Alas. W67	(9) N-15
Ingalls Cr.	Wash.	(—) Q-25
Inglutalik Riv.	Alas.	(21) G-7-8
Iniskin Riv.	Alas.	(16C) I-13
Inklin Riv.	Alas.	(—) N-14
Innoko Riv.	Alas.	(21) H-9-10
Iowithla Riv.	Alas.	(20) H-13
Ipewik Riv.	Alas.	(23) F-4
Ipmiluik Riv.	Alas.	(23) H-5
Ipnavik Riv.	Alas.	(23*) H-4
Irion Cr.	Alas.	(—) J-10
Irion Cr.	Wash.	(—) Q-26
Irish Cr.	Alas. 76	(—) K-12
Irish Cr.	Alas. E34C	(10) N-16
Issaquah Cr.	Wash.	(3) Q-25
Italio Riv.	Alas.	(14) M-13

Name	State	Location
Itkillik[8] Riv.	Alas.	(23*) J-2-3
Ivan Riv.	Alas.	(—) J-11
Ives Cr.	Alas. K172	(—) N-17
Jack Durand Cr. (Iliamna Lake)	Alas.	(—) I-13
Jackman Cr.	Wash.	(—) Q-24
Jackolof Cr.	Alas.	(16A) J-13
Jack Pot Riv.	Alas. 608	(—) J-12
Jackson Cr.	Alas. 613	(—) J-12
Jackson Cr.	Oreg.	(—) Q-30
Jap Cr.	Alas. WR1	(10) N-16
Jean Cr. and Lake	Alas.	(16A) J-12
Jean Cr.	Alas. 50K	(18) I-15
Jeanie Cr.	Alas. 784	(—) K-13
Jenkins Cr.	Wash.	(—) Q-25
Jenner Riv.	Calif.	(—) Q-34
Jennings Riv.	Alas.	(—) N-O-13
Jim Cr.	Alas.	(16B) J-11
Jim Cr.	Alas. K63	(7) N-17
Jim Cr.	Wash.	(—) Q-24
Joe Cr.	Wash.	(—) P-25
John Riv.	Alas.	(22) I-J-5
John Day Riv., and North, Middle, and South Forks	Oreg.	(4) Q-27-28, R-28
John's Cr.	Wash.	(—) Q-25
John's Riv.	Wash.	(—) Q-26
Johnson Cr. (Balboa Bay)	Alas.	(19) G-17
Johnson Cr.	Alas.	(16A) J-12
Johnson Cr.	Alas. 655	(—) J-12
Johnson Cr.	Alas.	(12) N-14
Johnson Cr.	Alas. K127	(8) N-18
Johnson Cr.	Oreg.	(—) P-30
Johnson Cr.	Oreg.	(—) Q-27
Johnson Riv.	Alas.	(16C) I-12
Johnson Riv.	Alas.	(22) K-9
Johnson Riv.	Alas.	(12) N-14
Johnson Cove Cr.	Alas. 119	(—) K-12
Johnstone Cr.	Alas. 823	(—) K-12
Jonah Cr.	Alas. 258	(—) K-11
Jones Cr.	Wash.	(—) Q-24
Jordan Cr.	Oreg.	(—) Q-27
Juania Cr.	Alas. 818	(—) K-12
Judd Lake	Alas.	(17) J-11
Junction Cr.	Alas. 618	(—) J-12
Juneau Cr.	Alas.	(16A) J-12
Kadak Cr.	Alas. E36	(9) N-16
Kadashan Cr.	Alas.	(—) N-15
Kaflia Cr.	Alas. 116K	(18) I-14
Kaguyak Cr.	Alas. 62K	(18) I-16
Kahiltna Riv.	Alas.	(17) J-10-11
Kah Shakes Cr.	Alas. K19	(7) O-17
Kah Sheets Cr.	Alas. WR62	(10) N-16
Kaina Cr.	Alas.	(15) K-11

[8] Shown as "Itillik" on map.

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APPENDIX I. Continued.

Name	State	Location
Kaiugnak Cr.	Alas. 51K	(18) I-15
Kake Cr.	Alas. 627	(—) J-12
Kake Cr.	Alas.	(—) N-16
Kakhonak Lake and Riv.	Alas.	(20) I-13
Kakhtul Riv.	Alas.	(20) H-13
Kaksu Riv.	Alas.	(23*) H-3
Kalakak Riv.	Alas.	(—) H-14
Kalama Riv.	Wash.	(4) Q-26
Kaliakh Riv.	Alas.	(15) L-12
Kaliguricheark Riv.	Alas.	(23) H-5
Kallarichuk Riv.	Alas.	(23) G-H-5
Kalsin Cr.	Alas. 21K	(18) I-15
Kalskag Riv.	Alas.	(—) G-11
Kamishak Riv.	Alas.	(16C) I-13-14
Kanayut Riv.	Alas.	(23*) J-3
Kandik Riv.	Alas.	(22) L-7
Kanektok Riv.	Alas.	(20) G-13
Kantishna Riv.	Alas.	(22) J-8
Kanuti Riv.	Alas.	(22) I-6
Kaolak Riv.	Alas.	(23*) H-3
Karluk Lake and Riv.	Alas. 88K	(18) I-15
Karta Riv.	Alas. K178	(8) N-17
Kashaiak Riv. and Lake	Alas.	(—) G-13
Kashegelok Riv.	Alas.	(—) H-12
Kashowrush Riv.	Alas.	(—) M-12
Kashunuk Riv.	Alas.	(20*) F-11
Kashvik Cr.	Alas. 125K	(18) I-15
Kashwitna Riv.	Alas.	(—) J-11
Kasilof Riv.	Alas.	(16A) J-12
Kaskanak Cr.	Alas.	(20) H-I-13
Kasook Lake Cr.	Alas. WC25	(8) N-17
Kateel Riv.	Alas.	(21) H-7
Katelnikoff Cr.	Alas. 112	(—) K-12
Katlian Riv. (Katlian[9] Bay)	Alas. W65A	(—) N-15
Katnu Riv.	Alas.	(16C) I-12
Katzehin Riv.	Alas.	(13) H-13
Kauk Riv.	Alas.	(23) G-6
Kaydas Cr.	Alas. 150	(15*) K-11
Kearney Cr.	Wash.	(—) Q-26
Kegan Cr.	Alas. K136	(—) N-17
Kejulik Riv. (Egegik System)	Alas.	(—) I-15
Kelly Cr.	Idaho	(—) S-26
Kelly Riv.	Alas.	(23) G-5
Kenai Lake and Riv.	Alas.	(16A) J-12
Kenibuma Cr. and Lake	Alas.	(—) I-11
Kennedy Cr.	Wash.	(—) Q-25
Kenny Cr.	Alas. 841	(15*) K-12
Keta Cr.	Alas. 83	(—) K-12
Keta Riv.	Alas. K24	(7) O-17
Ketchikan Cr.	Alas. K91	(—) O-17
Ketik Riv.	Alas.	(23*) H-2-3
Khotol Riv.	Alas.	(—) H-8
Kiagna Riv.	Alas.	(—) L-11
Kigalik Riv.	Alas.	(23*) I-3
Kijik Lake and Riv.	Alas.	(20) I-12
Kilchis Riv.	Oreg.	(—) Q-27
Kiliuda Cr.	Alas. 44K	(18) I-15
Killey Riv.	Alas.	(—) J-12
Killik Riv.	Alas.	(23*) H-4
Killillan Cr.	Oreg.	(—) Q-27
Kina Cr.	Alas. K174	(—) N-17
King Cr.	Alas. 829	(—) K-12
Kings Lakes and Riv.	Alas.	(16B) J-11
Kings Riv.	Alas. 487	(—) J-12
King Salmon Cr.	Alas.	(18) H-14
King Salmon Cr.	Alas.	(—) H-16
King Salmon Cr.	Alas.	(—) N-14
King Salmon Cr.	Alas. E12	(11) N-14
King Salmon Cr.	Alas. K44-2	(—) O-17
King Salmon Riv.	Alas.	(20) H-12
King Salmon Riv.	Alas.	(18) H-14
King Salmon Riv.	Alas.	(18) H-15
Kings County Cr.	Alas.	(16A) J-12
Kinia Riv.	Alas.	(20*) F-12
Kiniklik Cr.	Alas. 269	(—) K-12
Kipchuk Riv.	Alas.	(20*) H-12
Kirkwood Cr.	Alas. 93	(—) K-12
Kisaralik Riv.	Alas.	(20*) G-12
Kivalina Riv.	Alas.	(23) F-5
Kiwalik Riv.	Alas.	(23) G-7
Kizhuchia Cr.	Alas.	(—) N-16
Kizhuyak Cr.	Alas. 104K	(18) I-15
Klahini Riv.	Alas. K47	(7) O-16
Klakas Lake Cr.	Alas. WC5[10]	(8) N-17
Klàm Cr.	Alas. K82A	(—) O-17
Klamath Riv.	Calif.	(1) P-Q-31
Klaskanine Riv.	Oreg.	(4) Q-26
Klawak Cr.	Alas. WC39	(8) N-17
Klehini Riv.	Alas.	(13) M-N-13
Klickitat Riv.	Wash.	(4) Q-26-27
Klu Cr.	Alas. K82	(7) O-17
Kluklakiatna Riv.	Alas.	(21) H-9
Klutina Lake and Riv.	Alas.	(15) K-11
Klutuk Cr.[11]	Alas.	(20) H-13
Knik Riv.	Alas.	(16B) J-11
Knowls Cr.	Alas. 67	(—) K-12
Knutson Cr. (Iliamna Lake)	Alas.	(—) I-13
Kobuk Riv. and tributaries	Alas.	(23) G-H-5-6
Kogak Riv.	Alas.	(21) G-9
Kogoluktuk Riv.	Alas.	(23) H-5-6
Kogrukluk Riv.	Alas.	(—) H-12
Kokolik Riv.	Alas.	(23*) G-3
Koktuli Riv.	Alas.	(20) H-I-13
Kokwok Riv.	Alas.	(20) H-13
Kompkoff Riv.	Alas. 610	(15*) J-12

[9] Shown as "Katlin" on map.

[10] Shown as "5" on map.

[11] Shown as "R." on map.

Continued ..

Appendix I. Continued.

Name	State	Location
Koness Riv.	Alas.	(22) K-L-5
Kongakut Riv.	Alas.	(—) L-3
Kongarok Riv.	Alas.	(—) F-7
Kononoff Cr.	Alas. 625	(—) J-12
Kontrashibuna Lake	Alas.	(—) I-12
Kook Cr.	Alas. W16	(11) N-15
Koppen Cr.	Alas. 35	(15*) K-12
Koserefski Riv.	Alas.	(21) G-10
Koshin Riv.	Alas.	(—) O-14
Koyuk Riv.	Alas.	(21) G-7
Koyukuk Riv.	Alas.	(21, 22) H-I-6-7-8
Krause Cr.	Alas. 118	(—) K-12
Kuday's Cr.	Alas. WR35	(8) N-17
Kuguklik Riv.	Alas.	(20*) G-12
Kugururok Riv.	Alas.	(23) G-4
Kuk Riv.	Alas.	(—) H-2
Kukak Cr.	Alas. 113K	(18) I-14
Kukaklek Lake	Alas.	(20) I-13
Kukpowruk Riv.	Alas.	(23*) G-3
Kukpuk Riv.	Alas.	(22) F-4
Kulik Lake and Riv. (Wood Riv.)	Alas.	(—) I-13
Kulukak Lake and Riv.	Alas.	(—) H-13-14
Kumliun Cape creeks	Alas.	(—) H-16
Kuna Riv.	Alas.	(23*) H-4
Kunk Cr.	Alas. WR28[12]	(—) N-16
Kuparuk Riv.	Alas.	(23*) J-2-3
Kurupa Riv.	Alas.	(23*) I-4
Kushluk Riv.	Alas.	(—) G-12
Kushtaka Lake	Alas.	(15) K-12
Kuskokwim Riv. (mouth)	Alas.	(20) G-12
Kutchik Riv.	Alas.	(23*) J-3
Kuzitrin Riv.	Alas.	(21) F-7
Kvichak Riv.	Alas.	(20) H-13
Kwain Cr.	Alas. K110	(—) O-17
Kwatahein Cr.	Alas. E43F	(—) N-16
Kwethluk Riv.	Alas.	(20*) G-12
Kwik Cr.	Alas.	(—) M-13
Kwiniuk Riv.	Alas.	(21) G-8
LaCamas Cr.	Wash.	(—) Q-27
Lace Riv.	Alas.	(12) N-14
Lafayette Riv.	Alas. 321	(—) K-11
Lagoon Cr.	Alas.	(—) J-K-12
Lagoon Cr.	Alas. 99	(—) K-12
Lagoon Cr.	Alas. K154	(—) N-17
Laguna Cr.	Calif.	(—) Q-35
Lake Cr. (Iliamna Lake)	Alas.	(—) I-13
Lake Cr.	Alas.	(17) J-10-11
Lake Cr.	Alas. E10C	(12) N-14
Lake Cr.	Alas. K48-[13]	(7) O-16
Lake Cr.	Oreg.	(—) Q-28
Lake Cr.	Wash.	(—) Q-24
Lake Cr.	Wash.	(—) Q-26
Lake Eva Cr.	Alas. W36	(—) N-15
Lake Florence Cr.	Alas. W47	(11) N-15
Lake Kathleen Cr.	Alas. W45A	(11) N-15
Lambert Lagoon	Alas. 295	(15*) K-12
Laramie Cr. (Naknek Lake)	Alas.	(—) I-14
Larsen Cr. and Lake	Alas.	(—) J-10
Larsen Cr.	Alas. 669	(—) J-12
Laura Cr. (Afognak I.)	Alas.	(—) I-14
Laurel Lake	Alas.	(—) I-14
Lava Cr. (Cinder R.)	Alas.	(—) I-13
Lawrence Cr.	Oreg.	(—) R-28
Leask Cr.	Alas. K95	(—) O-17
Lefthand Bay streams (Balboa Bay)	Alas.	(—) G-17
Lemhi Riv.	Idaho	(6) S-27-28
Lemon Cr.	Alas.	(12) N-14
Leontovitch Cape creeks	Alas.	(19) G-17
Levshakoff Cr.	Alas. 121	(—) K-11
Lewis Riv.	Alas.	(16B) J-11
Lewis Riv.	Wash.	(4) Q-26-27
Lewis and Clark Riv.	Oreg.	(4) Q-26
Lighthouse Cr.	Alas. 800	(15*) K-12
Lilliwaup Cr.	Wash.	(—) Q-25
Limestone Cr.	Alas. E1	(12) N-14
Lincoln Cr.	Wash.	(—) Q-26
Little Riv. and Lake	Alas. 97K	(18) I-15
Little Riv.	Oreg.	(—) Q-29
Little Bear Cr. (Newhalen Riv.)	Alas.	(—) I-13
Little Black Riv.	Alas.	(22) K-L-6
Little Bremner Riv.	Alas.	(—) K-11
Little Butte Cr.	Oreg.	(—) Q-30
Little Delta Riv.	Alas.	(22) K-8
Little Fall Cr.	Oreg.	(—) Q-29
Little Gibraltar Cr.	Alas.	(—) I-13
Little Hanna Lake	Alas.	(—) L-12
Little Indian Cr.	Alas.	(16B) J-12
Littlejohn Lagoon	Alas.	(—) G-17
Little Kamishak Riv.	Alas.	(16C) I-13
Little Kitoi Lake Cr.	Alas. 7K-1	(18) I-14
Little Klickitat Riv.	Wash.	(—) Q-26-27
Little Lagoon Cr. (Karluk Lake)	Alas.	(—) I-15
Little Martin Lake	Alas.	(—) K-12
Little Muddy Cr. (Naknek Lake)	Alas.	(—) H-14
Little Nestucca Riv.	Oreg.	(—) Q-27
Little Norway Cr.	Alas.	(—) G-17
Little Nothing Cr. (Naknek Lake)	Alas.	(—) H-14
Little Pilchuck Riv.	Wash.	(—) Q-24-25
Little Pistol Cr.	Idaho	(—) S-28
Little Quilcene Riv.	Wash.	(—) Q-25
Little Roadhouse Cr. (Iliamna Lake)	Alas.	(—) I-13
Little Salmon Riv.	Idaho	(6) R-27

Continued ...

[12] Shown as "28" on map.

[13] Shown as "K48" on map.

APPENDIX I. Continued.

Name	State	Location
Little Shasta Riv.	Calif.	(—)Q-31
Little Soos Cr.	Wash.	(—)Q-25
Little Susitna Riv.	Alas.	(16B)J-11
Little Togiak Lake, Riv., and creeks (Wood Riv.)	Alas.	(—)H-13
Little Tonsina Riv.	Alas.	(—)K-11
Little Weiser Riv.	Idaho	(—)R-28
Little Wenatchee Riv.	Wash.	(—)Q-25
Little White Salmon Riv.	Wash.	(—)Q-27
Little Willow Cr.	Alas.	(—)J-11
Lochsa Riv.	Idaho	(—)S-26
Logger's Cr.	Alas. 706	(—)K-13
Logging Camp Cr.	Alas. 435	(—)J-12
Log Jam Cr.	Alas.	(—)N-16-17
Logy Cr.	Wash.	(—)Q-26
Lone King Cr.	Alas.	(16B)J-11
Long Cr.	Alas. 214	(—)K-12
Long Lake	Alas.	(15)L-11
Long Arm Cr.	Alas. 29K	(18)I-15
Long John Lagoon	Alas.	(—)G-17
Loomis Cr.	Alas. 506	(—)J-K-12
Loon Cr.	Idaho	(—)S-28
Loon Cr.	Oreg.	(—)Q-29
Loring Cr.	Alas. K86	(—)O-17
Lost Cr.	Alas.	(22)K-6
Lost Cr.	Alas.	(14)M-13
Lost Cr.	Oreg.	(—)Q-29
Lost Cr.	Wash.	(—)Q-24
Lost Cr.	Wash.	(—)Q-26
Lost Lake	Alas.	(16A)J-12
Lostine Cr.	Oreg.	(6)R-27
Louis Cr.	Alas. 689	(—)K-12
Loveless Cr.	Alas. WR66	(—)N-16
Lowe Riv.	Alas. 137	(15*)K-11
Lower Talarik Cr. (Iliamna Lake)	Alas.	(—)I-13
Lucas Cr.	Wash.	(—)Q-26
Lucky Cr.	Alas. K105	(7)O-17
Mabel Cr.	Alas. WC9	(8)N-18
Macleod Cr.	Alas. 707	(—)K-13
Mad Riv.	Calif.	(1)P-Q-32
Mad Riv.	Wash.	(—)Q-24
Mahlo Riv.	Alas.	(—)K-11
Mahoney Cr.	Alas. K93	(—)O-17
Main Cr.	Alas.	(—)H-16
Main Riv.	Alas. 503	(—)J-12
Makarka Cr.	Alas. 844	(—)K-12
Makushin Riv. (Makushin Bay)	Alas.	(25)F-19
Malina Cr. and Lake	Alas. 1K	(18)I-14
Mallard Cr.	Alas. 698	(—)K-12
Mamby Cr.	Alas.	(—)L-13
Manastash Cr.	Wash.	(—)Q-26
Mangoak[14] Riv.	Alas.	(23)G-6
Manker Cr.	Alas.	(15)K-11
Mankomen Lake	Alas.	(15)K-9-10
Manning Cr.	Oreg.	(—)R-28
Manzanita Cr.	Alas. K74	(—)O-17
Marble Cr.	Alas. WR92	(8)N-16
Margaret Cr.	Alas. K85	(7)O-17
Margot Cr. (Naknek Lake)	Alas.	(—)I-14
Marie Cr. (Egegik System)	Alas.	(—)I-15
Marka Cr.	Alas. 12K	(18)I-14
Marsh Cr.	Alas.	(16C)I-13
Marsh Cr.	Idaho	(—)S-28
Marten Cr.	Alas. WR7	(7)O-16
Marten Riv.	Alas. K23	(7)O-17
Martin Lake and Riv.	Alas.	(15)K-12
Matanuska Riv.	Alas.	(16B)J-11
Mattole Riv.	Calif.	(1)P-32
Mauneluk Riv.	Alas.	(23)H-6
Max Cr.	Alas. WC4	(—)N-18
May Cr.	Wash.	(—)Q-25
Maybeso Cr.	Alas. K177	(8)N-17
Maynard Cr.	Wash.	(—)Q-24
McArthur Riv.	Alas.	(16B, 16C)J-12
McClure Cr.	Alas. 498	(—)J-12
McHenry Lake Cr.	Alas. WR37	(—)N-16
McKenzie Riv.	Oreg.	(4)Q-28
McKernan Cr.	Alas. 771	(—)K-12
McKlintock Riv.	Alas.	(—)N-12
McLees Lake	Alas.	(25)F-19
McMillan Riv.	Alas.	(—)N-10
McNaughton Riv.	Alas.	(—)N-13
McNeil Lake and Riv.	Alas.	(16C)I-13
Meacham Cr.	Alas. 430	(15*)J-12
Meachin Cr.	Oreg.	(—)R-27
Meade Riv.	Alas.	(23*)H-2
Meadow Cr. (Karluk Lake)	Alas.	(—)I-15
Meadow Cr.	Alas.	(16B)J-11
Meadow Cr.	Idaho	(—)S-26-27
Melozitna Riv.	Alas.	(21)I-7-8
Mendatine Riv.	Alas.	(—)K-11
Mendeltna Riv.	Alas.	(15)K-10
Mendenhall Lake	Alas.	(12)N-14
Menefee Cr.	Alas. WR32	(8)N-16
Mentanontli Riv.	Alas.	(22)I-6
Mentasta Lake	Alas.	(15)L-10
Merced Riv.	Calif.	(1)Q-35
Meshik Lake and Riv.	Alas.	(18, 19)H-16
Methany Riv.	Wash.	(—)P-Q-25
Methow Riv.	Wash.	(5)Q-24
Metolius Riv.	Oreg.	(4)Q-28
Meyers Cr.	Alas. K65	(—)N-17
Miam Lake (Portage Cr.)	Alas.	(—)I-15
Miami Riv.	Oreg.	(—)Q-27
Middle Cr.	Alas. 30	(19)G-17
Middle Cr.	Alas.	(—)N-16

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[14] Shown as "Mango" on map.

Continued ...

APPENDIX I. Continued.

Name	State	Location
Middle Lagoon	Alas.	(—)G-17
Middle Talarik Cr. (Iliamna Lake)	Alas.	(—)I-13
Midway Bay Riv.	Alas. 45K	(18)I-15
Mikchalk Lake	Alas.	(—)H-13
Mikfik Cr.	Alas.	(16C)I-13
Mill Cr.	Alas. 421	(—)J-12
Mill Cr.	Alas. WR5	(—)N-16
Mill Cr.	Calif.	(1)P-31
Mill Cr.	Calif.	(1)Q-32
Mill Cr.	Calif.	(—)Q-35
Mill Cr.	Oreg.	(—)Q-26-27
Mill Cr.	Oreg.	(—)Q-30
Mill Cr.	Oreg.	(—)R-27-28
Mill Cr.	Wash.	(—)Q-25
Mill Cr.	Wash.	(—)Q-26
Mill Cr.	Wash.	(—)Q-26
Mill Cr.	Wash.	(—)R-28
Millard Cr.	Alas. 115	(15*)K-12
Miller Cr.	Alas. K138	(—)N-17
Millwood Cr.	Oreg.	(—)Q-29
Milk Cr.	Oreg.	(—)Q-27
Milton Cr.	Oreg.	(—)Q-27
Minam Cr.	Oreg.	(6)R-27
Mineral Cr.	Alas. 147	(—)K-11
Miner's Lake	Alas.	(—)K-12
Miner's Riv.	Alas. 244	(—)K-11
Mink Cr. (Iliamna Lake)	Alas.	(—)I-13
Mink Cr.	Alas. 480	(—)J-12
Mink Cr.	Alas. K21A	(—)O-17
Mino Cr.	Alas. 33	(19)G-17
Mint Riv.	Alas.	(23)F-7
Minter Cr.	Wash.	(—)Q-25
Miss 42 Cr. (Naknek Lake)	Alas.	(—)H-14
Mission Cr.	Wash.	(—)Q-25
Moclips Riv.	Wash.	(—)P-25
Moffet Bay creeks	Alas.	(19)G-17
Mohawk Cr.	Oreg.	(—)Q-28
Mokelumne Riv.	Calif.	(1)Q-34
Molalla Riv.	Oreg.	(4)Q-27
Mole Riv.	Alas. E15	(11)N-15
Monashka Cr.	Alas. 15K	(18)I-15
Montague Cr.	Alas. 726	(—)K-12
Montana Cr.	Alas.	(—)J-10-11
Montgomery Cr.	Alas. 670	(—)J-13
Monument Cr.	Alas.	(16B)K-11
Monumental Cr.	Idaho	(—)S-27
Moore Cr. (Ugashik Lake)	Alas.	(—)H-15
Moose Cr.	Alas.	(16B)J-11
Moose Cr.	Alas.	(16A)J-12
Moose Cr.	Alas.	(16A)J-12
Moose Cr.	Alas. E9F	(—)N-14
Moose Cr.	Idaho	(—)S-26
Moose Lake	Alas.	(—)I-13
Moose Riv.	Alas.	(16A)J-12
Moraine Cr.	Alas.	(—)I-13
Moraine Cr. (Karluk Lake)	Alas.	(—)I-15
Morley Riv.	Alas.	(—)N-O-12
Morsby Cr.	Oreg.	(—)Q-29
Moser Cr.	Alas. K89	(—)O-17
Moses Riv.	Alas.	(—)G-7-8
Mosquito Cr.	Alas. 402	(—)J-11
Moss Cr.	Oreg.	(—)Q-27
Most Cr.	Alas. 493	(—)J-12
Mother Goose Lake	Alas.	(18)H-15
Mud Cr.	Alas.	(15)K-9
Mud Lake	Alas.	(16B)J-11
Mud Lake	Alas.	(16A)J-12
Mud Bay Cr. (Port Moller)	Alas.	(19)G-17
Muddy Cr.	Alas. 842	(15*)K-12
Muddy Riv.	Alas. E7A	(10)N-16
Mulchatna Riv.	Alas.	(20)H-I-12
Munson Cr.	Oreg.	(—)Q-27
Murder Cr. and Lake	Alas.	(—)J-10
Mush Lake	Alas.	(—)M-12
Myrtle Cr.	Oreg.	(—)P-Q-29-30
Mystery Cr.	Alas.	(—)J-12
Naches[15] Riv.	Wash.	(5)Q-26
Nacktan Cr.	Alas. 602	(—)J-12
Nageethluk Riv.	Alas.	(21)G-10
Nagishlamina Riv.	Alas.	(—)I-11
Naha Riv.	Alas. K87	(7)O-17
Nakat Cr.	Alas. K13	(7)O-18
Naked Cr.	Alas. 296	(15*)K-12
Nakina Riv.	Alas.	(—)N-14
Naknek Lake, and unnamed creeks	Alas.	(18)H-I-14
Naknek Riv.	Alas.	(18)H-14
Nancy Cr. (Iliamna Lake)	Alas.	(—)I-13
Nancy Cr. and Lake	Alas.	(16B)J-11
Nanuktuk Cr.	Alas.	(—)I-13
Naomoff Cr.	Alas. 127	(—)K-11-12
Napotoli Cr.	Alas.	(—)H-13
Narogurum Riv.	Alas.	(20)H-13
Narrow Pass Cr.	Alas. K68	(7)O-18
Narrows Cr.	Alas. 75K	(18)I-15
Narrows Cr.	Alas. 471	(—)J-12
Naselle Riv.	Wash.	(3)Q-26
Nason Cr.	Wash.	(—)Q-25
Nation Riv.	Alas.	(22)L-7
Naukati Cr.	Alas. WC54	(—)N-17
Navarro Riv.	Calif.	(1)Q-33
Navy Cr.	Alas. WR38	(—)N-16
Necanicum Riv.	Oreg.	(2)Q-27
Neck Cr.	Alas.	(—)N-16
Neets Cr.	Alas. K83[16]	(7)O-17

[15] Shown as "Nache" on map.

[16] Shown as "K13" on map.

Continued

Appendix I. Continued.

Name	State	Location
Nehalem[17] Riv.	Oreg.	(2)Q-27
Nellie Martin Riv.	Alas. 779	(—)K-13
Nellie Juan Riv.	Alas. 488	(—)J-12
Nelson Cr.	Alas. 15	(15*)K-12
Nelson Lagoon	Alas.	(—)G-17
Nelson Riv. and tributaries	Alas.	(19)G-17
Nemah Riv.	Wash.	(—)Q-26
Nenana Riv.	Alas.	(22)J-8
Nerka Lake and creeks (Wood Riv.)	Alas.	(—)H-13
Neskowin Cr.	Oreg.	(—)Q-27
Nestucca Riv.	Oreg.	(2)Q-27
Neta Riv.	Alas.	(—)Q-17
New Cr.	Oreg.	(—)P-30
New Riv.	Calif.	(1)Q-32
Newaukum Cr.	Wash.	(—)Q-25
Newaukum Riv.	Wash.	(3)Q-26
Newhalen Riv. (Lake Clark)	Alas.	(—)I-13
Neva Cr.	Alas. 12	(13)N-14
Newskah Cr.	Wash.	(—)Q-26
Niblack Cr.	Alas. K62	(7)N-17
Nicholas Lake	Alas.	(25)A-20
Nick G. and Nick N. Crs. (Iliamna Lake)	Alas.	(—)I-13
Nicolet Cr.	Alas. 3	(—)K-12
Nigelius Cr.	Alas. K98	(—)O-17
Nigisaktuvik Riv.	Alas.	(23*)H-2
Nigu Riv.	Alas.	(23*)H-4
Nikolai Cr.	Alas.	(16B, 16C)J-11
Nikolai Cr.	Alas.	(16A)J-12
Nimiuktuk Riv.	Alas.	(23)H-4
Ninigiak Riv.	Alas. 110K	(18)I-14
Ninilchik Riv.	Alas.	(16A)J-12
Nishlik Lake	Alas.	(20)H-12
Nisqually Riv.	Wash.	(3)Q-25-26
Nisutlin Riv.	Alas.	(—)N-12
Niukluk Riv.	Alas.	(21)F-G-8
Noatak Riv. and tributaries	Alas.	(23)G-H-4-5
Nome Riv.	Alas.	(21)F-8
Nonvianuk Lake	Alas.	(20)I-13
Nooksack Riv.	Wash.	(3)Q-24
Nooya Cr.	Alas. K42	(—)O-17
North Cr.	Alas. 685	(15*)K-12
North Riv.	Alas.	(21)G-8-9
North Riv.	Wash.	(3)Q-26
North Alinchak Cr.	Alas. 127K	(18)I-15
North Arm Cr.	Alas. WR3-2	(—)N-16
North LaGorce Cr. (Naknek Lake)	Alas.	(—)I-14
Northwest Woody 1 and 2 (Iliamna Lake)	Alas.	(—)I-13
No Shot Cr. (Naknek Lake)	Alas.	(—)H-14
Nowitna Riv.	Alas.	(21)I-8-9
Noyo Riv.	Calif.	(1)Q-33
Nuchek Cr.	Alas. 812	(—)K-12
Nuka Riv.	Alas.	(16A)J-13
Nuka Island streams (Nuka Bay)	Alas.	(16A)J-13
Nukayachugak Riv.	Alas.	(—)H-14
Nulato Riv.	Alas.	(21)H-8
Nuluk Riv.	Alas.	(23)F-7
Nunavaugaluk Lake	Alas.	(20)H-13
Nushagak Riv.	Alas.	(20)H-13-14
Nutkwa Cr.	Alas. WC11	(8)N-17
Nuyakuk Lake and Riv.	Alas.	(20)H-13
"O" Cr. (Naknek Lake)	Alas.	(—)I-14
Oak Cr.	Oreg.	(—)Q-29
O'Brien Cr.	Alas. 666	(—)J-12
Ocean Dock Cr.	Alas. 7	(—)K-12
Ohmer Cr.	Alas. WR57	(10)N-16
Oil Lakes and Riv.	Alas.	(—)H-16
Okanogan Riv.	Wash.	(5)R-23-24
Old Franks Cr.	Alas. K170	(—)N-17
Old Man Cr.	Alas.	(20)H-12-13
Old Man Lake	Alas.	(15)K-10
Old Man's Cr.	Alas. E21	(—)N-15
Old Toms Cr.	Alas. K163	(—)N-17
Old Williams Cr. (Iliamna Lake)	Alas.	(—)I-13
Oleney Cr.	Wash.	(—)Q-25
Olequa Cr.	Wash.	(—)Q-26
Olga Cr.	Alas. 79K	(18)I-15
Olsen Cr.	Alas. 51	(—)K-12
O'Malley Lake and Riv. (Karluk Lake)	Alas.	(—)I-15
Omar Cr.	Alas. K162	(8)N-17
One Shot Cr. (Brooks Lake)	Alas.	(—)I-14
Ongivinuck Lake and Riv.	Alas.	(—)H-13
Oolamnagavik Riv.	Alas.	(23*)I-4
Orca Cr.	Alas. 863	(—)K-12
Orchard Cr.	Alas.	(7)O-17
Orleans Cr.	Calif.	(—)Q-31
Orofio Cr.	Calif.	(—)Q-31
Orzenoi Riv.	Alas.	(—)G-17
Osoyoos Lake	Wash.	(—)R-23-24
Otter Cr. (Bechar of Lake)	Alas.	(—)H-15
Ozette Cr. and Lake	Wash.	(—)P-24
Pablo Cr.	Alas. 633	(—)J-12
Pack Cr.	Alas. E13A	(11)N-15
Packer Cr.	Calif.	(—)Q-31
Packers Lake	Alas.	(16C)J-12
Paddy Cr.	Alas. 601	(—)J-11
Pah Riv.	Alas.	(23)H-6
Pahsimeroi Riv.	Idaho	(—)S-28
Paidaloe Riv.	Calif.	(—)Q-34
Paint Riv.	Alas.	(16C)I-13

[17] Shown as "Nehalam" on map.

Continued ...

APPENDIX I. Continued.

Name	State	Location
Painter Cr. (Mother Goose Lake)	Alas.	(—)H-15
Palix Cr.	Wash.	(—)Q-26
Palmer Cr.	Alas.	(16B)J-11
Panjab Cr.	Wash.	(—)R-26
Panther Cr.	Idaho	(—)S-27
Panther Cr.	Oreg.	(—)Q-27
Panther Cr.	Wash.	(—)Q-27
Papoose Cr.	Alas. 292	(—)K-12
Paramanof Lake	Alas.	(—)I-14
Paramanof Lagoon Cr.	Alas. 2K	(18)I-14
Paris Cr.	Alas.	(—)H-15
Park Cr.	Alas.	(16C)I-13
Parks Cr.	Alas. 458	(—)J-12
Pasagshak Cr.	Alas. 24K	(18)I-15
Pass Cr.	Alas. 41	(—)K-12
Passage Cr.	Alas. 639	(—)J-12
Patton Cr.	Alas. 782	(—)K-13
Pauls Cr.	Alas.	(—)H-14
Pauls Lake Cr.	Alas. 6K	(—)I-14
Paulson Cr.	Alas. 455	(15*)J-12
Pautzke Cr.	Alas. 775a	(15*)K-12
Pavalof Cr. and Lake	Alas.	(—)N-15
Pawn Cr.	Oreg.	(—)P-Q-28-29
Payette Riv.	Idaho	(—)R-28
Peace Riv. (Wood Riv.)	Alas.	(—)H-13
Peaceful Riv. (Attu I.)	Alas.	(25)A-20
Pearl Cr. (Ugashik Lake)	Alas.	(—)H-15
Pecks Cr. (Kvichak Riv.)	Alas.	(—)H-I-13
Pedro Cr. (Iliamna Lake)	Alas.	(—)I-13
Pellew Cr.	Alas. 270	(15*)K-12
Pelly Riv.	Alas.	(—)M-10
Penny Riv.	Alas.	(—)F-8
Percival Cr.	Wash.	(—)Q-25
Perenosa Cr.	Alas. 5K	(18)I-14
Perkins Cr.	Alas. K128	(—)N-18
Peschan Riv.	Alas. W35	(9)N-15
Peshastin Cr.	Wash.	(—)Q-25
Pestchani Cr. (Kodiak, Marmot Bay)	Alas.	(—)I-15
Pete Andrew Cr. (Iliamna Lake)	Alas.	(—)I-13
Peters Cr.	Alas.	(16B)J-11
Petersburg Cr.	Alas. WR56	(10)N-16
Peterson Cr.	Alas. E10B	(12)N-14
Phonograph Cr.	Alas. W76	(11)M-N-15
Pigot Riv.	Alas. 431	(—)J-12
Pikmiktalik Riv.	Alas.	(21)G-9
Pilchuck Riv.	Wash.	(3)Q-24-25
Pile Riv. (Iliamna Lake)	Alas.	(—)I-13
Piledriver Cr.	Alas. E43B	(9)N-16
Pillar Cr.	Alas. 16K	(18)I-15
Pincher Cr.	Alas.	(16B)J-12
Pine Cr.	Alas. WR102	(8)N-16
Pine Cr.	Idaho	(—)R-28
Pine Cr.	Oreg.	(—)R-28
Pine Lake	Alas.	(—)M-12
Pinguk Riv.	Alas.	(23)F-7
Pirate Cr.	Alas. 428	(—)J-12
Pistol Riv.	Oreg.	(—)P-30
Pitmegea Riv.	Alas.	(23)F-4
Placer Riv.	Alas.	(16B)J-12
Plateau Cr.	Alas. 45	(—)K-12
Poe Riv.	Alas. 436	(—)J-12
Point Cr.	Alas. 702	(—)K-13
Point Riv.	Alas.	(—)I-13
Point Reyes Cr.	Calif.	(—)Q-34
Polk Cr.	Alas. K165	(8)N-17
Polly Cr.	Alas.	(16C)I-12
Pond Cr.	Alas. K106	(7)O-18
Pope Cr. (Iliamna Lake)	Alas.	(—)I-13
Porcupine Cr.	Alas. WR42	(8)N-16
Porcupine Riv.	Alas.	(22)K-L-6
Portage Cr. (Herendeen Bay)	Alas.	(19)G-17
Portage Cr.	Alas.	(—)J-10
Portage Cr.	Alas.	(16B)J-12
Portage Cr.	Alas. WC14	(8)N-17
Portage Cr.	Alas. K77	(7)O-17
Portage Bay Cr.	Alas. 25K	(18)I-15
Port Camden Cr.	Alas. E35	(9)N-16
Port Chatham streams	Alas.	(16A)J-13
Port Dick streams	Alas.	(16A)J-13
Porter Cr.	Wash.	(—)Q-26
Porterfield Cr.	Alas.	(7)N-16
Port Graham streams	Alas.	(16A)J-13
Port Heiden creeks	Alas.	(18)H-16
Port Nellie Juan Cr.	Alas. 500	(15*)J-12
Potlatch Riv.	Idaho	(—)R-26
Powder Riv.	Oreg.	(6)R-28
Powell Cr.	Wash.	(—)Q-24
Power House Cr.	Alas.	(—)N-16
Prairie Cr.	Alas.	(17)J-10
Prairie Cr.	Wash.	(—)Q-25
Preacher Cr.	Alas.	(22)K-6-7
Price Riv.	Alas.	(23*)I-3
Prince Cr. Ponds (Iliamna Lake)	Alas.	(—)I-13
Princeton Cr.	Alas. 617	(—)J-12
Prospect Cr.	Alas. E1A	(12)N-14
Ptarmigan Cr.	Alas.	(16A)J-12
Pudding Riv.	Oreg.	(4)Q-27
Puget Lake	Alas. 646	(—)J-13
Puget Riv.	Alas. 649	(—)J-12
Pungokepuk Cr. and Lake	Alas.	(20)H-13
Puyallup Riv.	Wash.	(3)Q-25
Pysht Riv.	Wash.	(—)P-24
Quadra Cr.	Alas. 711	(—)K-13
Quartz Cr.	Alas.	(—)F-7
Quartz Cr.	Alas.	(16A)J-12
Quartz Cr.	Alas.	(—)K-11
Quartz Cr.	Wash.	(—)Q-26

Continued ...

Appendix I. Continued.

Name	State	Location
Quartzville Cr.	Oreg.	(—)Q-28
Queets Riv.	Wash.	(3)P-Q-25
Question and Answer Lakes	Alas.	(—)J-10
Quilcene[18] Riv.	Wash.	(3)Q-25
Quillayute Riv.	Wash.	(—)P-25
Quinault Lake and Riv.	Wash.	(3)P-Q-25
Rabbit Cr.	Alas.	(16B)J-11
Racehorse Cr.	Wash.	(—)Q-24
Raft Riv.	Wash.	(—)P-25
Raging Riv.	Wash.	(—)Q-25
Rainbow Cr.	Alas. 98	(—)K-12
Rainy Cr.	Alas. 459	(—)J-12
Rams Cr.	Alas.	(—)G-17
Ranch Cr.	Alas. 109	(—)K-12
Rapid Riv.	Idaho	(—)R-27
Rapid Riv.	Wash.	(—)S-28
Rattlesnake Cr.	Wash.	(—)Q-26
Ray Cr. (Cinder Riv.)	Alas.	(—)I-13
Raymond Cr.	Alas. K57	(7)O-17
Red Cr.	Alas. 300	(—)K-12
Red Riv.	Alas. 83K	(18)I-15
Red Riv.	Alas. K23A	(7)O-17
Red Boat Cr. (Ugashik Lake)	Alas.	(—)H-15
Red Cabin Cr.	Wash.	(—)Q-24
Red Cap Cr.	Alas.	(—)N-14
Redfish Cr. and Lake	Idaho	(6)S-28
Red Mountain Cr.	Calif.	(—)Q-31
Redoubt Lake	Alas.	(9)N-16
Red River Lake (Kodiak)	Alas.	(—)I-15
Red Salmon Cr.	Alas.	(—)N-16
Red Salmon Lake	Alas.	(—)I-J-11
Red Shirt Lake	Alas.	(17)J-11
Redwood Cr.	Calif.	(1)P-Q-31
Reindeer Cr.	Alas.	(—)I-13
Reindeer Riv.	Alas.	(21)G-11
Reindeer Riv.	Alas.	(21)H-10
Resurrection Cr.	Alas.	(16B)J-12
Resurrection Riv.	Alas.	(16A)J-12
Rickreall Cr.	Oreg.	(4)Q-28
Robbers Cr.	Alas. 465	(—)J-12
Robertson Riv.	Alas.	(22)K-9
Robinson Cr.	Alas. K45	(—)O-17
Robinson Cr.	Idaho	(—)R-26
Rock Cr.	Alas. 94	(—)K-12
Rock Cr.	Alas. K166	(—)N-17
Rock Cr.	Oreg.	(—)P-28
Rock Cr.	Oreg.	(—)P-30
Rock Cr.	Oreg.	(—)Q-29
Rock Cr.	Oreg.	(—)Q-30
Rock Cr.	Wash.	(—)Q-25
Rock Cr.	Wash.	(—)Q-27
Rocky Cr.	Alas. 759	(—)K-12
Rocky Riv.	Alas.	(16A)J-13
Rodman Cr.	Alas. W33	(9)N-15
Rogue Cr.	Alas. 21	(—)K-12
Rogue Riv.	Oreg.	(2)P-Q-30
Ro Le Jo Cr. and Lake	Alas.	(—)J-11
Rollin Cr.	Alas. 849	(—)K-12
Rose Cr.	Alas. WC23	(8)N-18
Rose Tead Lake (Pasagshak Cr.)	Alas.	(—)I-15
Rosswog Cr.	Alas. 774	(—)K-12
Rowi Riv.	Oreg.	(—)Q-29
Rude Riv.	Alas. 16	(—)K-12
Rudyerd Riv.	Alas. K41	(7)O-17
Russell Cr.	Alas. 738	(—)K-12
Russian Cr. (Iliamna Lake)	Alas.	(—)I-13
Russian Riv.	Alas. 67K	(18)I-15
Russian Riv. and Lakes	Alas.	(16A)J-12
Russian Riv.	Calif.	(1)Q-33-34
Ruth Lake and Riv. (Becharof Lake)	Alas.	(—)H-15
Sacramento Riv.	Alas. 23K	(18)I-15
Sacramento Riv. (mouth)	Calif.	(1)Q-34
Sagavanirktok Riv.	Alas.	(23*)J-2-3
Saginaw Cr.	Alas. E39	(—)N-16
Saint Anne Cr.	Alas.	(15)K-11
Saint John Cr.	Alas. WR49	(8)N-16
Saint Matthews Cr.	Alas. 56	(—)K-12
Saks Cr.	Alas. K46	(7)O-17
Salcha Riv.	Alas.	(22)K-8
Salinas Riv.	Calif.	(—)Q-36
Salmon Cr. (Becharof Lake)	Alas.	(—)H-15
Salmon Cr. (Karluk Lake)	Alas.	(—)I-15
Salmon Cr.	Alas.	(16A)J-12
Salmon Cr.	Alas. E10D	(12)N-14
Salmon Cr.	Alas.	(9)N-16
Salmon Cr.	Calif.	(—)Q-34
Salmon Cr.	Oreg.	(—)P-30
Salmon Cr.	Oreg.	(2)Q-27
Salmon Cr.	Wash.	(—)Q-26
Salmon Cr.	Wash.	(—)Q-26
Salmon Cr.	Wash.	(—)Q-27
Salmon Lake	Alas.	(21)F-8
Salmon Riv.	Alas.	(23)H-5
Salmon Riv.	Alas.	(20*)H-11-12
Salmon Riv.	Alas. I26	(13)N-14
Salmon Riv.	Alas. K1	(7)O-17
Salmon Riv.	Calif.	(1)Q-31
Salmon Riv., and South and Middle Forks	Idaho	(6)R-S-27, S-28
Salmon Riv.	Oreg.	(—)Q-27
Salmon Riv.	Wash.	(—)P-25
Salonie Riv.	Alas. 19K	(18)I-15
Salt Cr.	Alas. K96	(—)O-17
Saltery Cr.	Alas. K160	(8)N-17
Saltery Cr. and Lake	Alas. 26K	(18)I-15
Samish Riv.	Wash.	(3)Q-24

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[18] Shown as "Quicene" on map.

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APPENDIX I. Continued.

Name	State	Location
Sammamish Lake and Slough	Wash.	(—)Q-25
San Benito Riv.	Calif.	(—)Q-36
Sand Cr.	Alas.	(—)H-13
Sandfly Cr.	Alas. K5	(7)O-17
Sand Lake Cr.	Oreg.	(—)Q-27
Sandy Cr.	Oreg.	(—)Q-29
Sandy Lake and Riv.	Alas.	(19)G-16
Sandy Riv.	Oreg.	(4)Q-27
San Joaquin Riv.	Calif.	(1)Q-34-35
San Juan Cr.	Alas.	(—)K-13
San Lorenzo Riv.	Calif.	(1)Q-35-36
Santa Anna Cr.	Alas. WR17	(—)O-17
Santiam Riv.	Oreg.	(4)Q-28
San Vicente Cr.	Calif.	(—)Q-35
Sargent Cr.	Alas. 18K	(18)I-15
Saposa Cr.	Alas. 7K	(18)I-15
Sarkar Cr.	Alas. WC56	(8)N-17
Sashin Cr.	Alas. E49	(9)N-16
Satsop Riv.	Wash.	(3)Q-25
Satus[19] Cr.	Wash.	(5)Q-26
Sauk Riv.	Wash.	(—)Q-24
Savonoski Riv. (Naknek Lake)	Alas.	(—)I-14
Sawmill Cr.	Alas. 133	(—)K-11
Sawmill Riv.	Alas.	(12)N-14
Scappoose Cr.	Oreg.	(4)Q-27
Scenery Cr.	Alas. E8	(10)N-15
Schooner Cr.	Alas. 777	(—)K-12
Schoppe Cr.	Alas. 273	(—)K-12
Schuman Cr.	Alas. 746	(—)K-12
Scoggin Cr.	Oreg.	(—)Q-27
Scott Cr.	Alas. 835	(—)K-12
Scott Cr.	Calif.	(1)Q-35
Scott Riv.	Calif.	(—)Q-31
Seagull Cr.	Alas. I17	(11)N-14-15
Seal Cr.	Alas.	(14)M-13
Seal Riv.	Alas.	(15)L-12
Sea Level Cr.	Alas. K104	(7)O-17
Seattle Cr.	Alas.	(16B)J-12
Sedie Riv.	Alas.	(—)J-13
Seepage Cr.	Alas.	(16A)J-12
Seiad Cr.	Calif.	(—)Q-31
Selawik Riv.	Alas.	(23)H-6
Seldovia Riv.	Alas.	(16A)J-13
Selway Riv.	Idaho	(—)S-26-27
Sere Cr.	Alas. 222	(—)K-12
Serpentine Riv.	Alas.	(23)F-6-7
Settler Cove Cr. and Lake (Kodiak, Marmot Bay)	Alas.	(—)I-15
Seven Rivers	Alas. 65K	(18)I-16
Seventymile Riv.	Alas.	(22)L-8
Shad Cr.	Alas. 749	(—)K-12
Shaheen Cr.	Alas. WC51	(8)N-17
Shaishnikof[20] Riv.	Alas.	(25)F-19
Shakespeare Cr.	Alas. 440	(15*)J-12
Shaktolik Riv.	Alas.	(21)G-8
Shale Cr.	Alas. 92	(—)K-12
Shasta Riv.	Calif.	(1)Q-31
Shaw Cr.	Alas.	(22)K-8
Shearwater Cr.	Alas. 42K	(18)I-15
Sheenjek Riv.	Alas.	(22)L-4-5, K-5-6
Sheep Cr.	Alas.	(—)J-10-11
Sheep Cr.	Alas.	(16A)J-13
Sheep Riv.	Alas.	(17)J-10
Sheep Riv.	Alas. 36	(—)K-12
Shell Cr. and Lake	Alas.	(17)J-11
Shelokum Cr.	Alas. K53	(—)O-17
Shelter Cr.	Alas. 663	(—)K-12
Shepard Cr.	Alas. 12	(—)K-12
Sheridan Cr.	Alas. K31B	(7)O-17
Sheslan Riv.	Alas.	(—)N-14
Ship Cr.	Alas.	(16B)J-11
Shipley Cr.	Alas. WR91	(8)N-16
Shipyard Cr.	Alas. 499	(—)J-12
Shirley Lake	Alas.	(—)I-J-11
Shitike Cr.	Oreg.	(—)Q-28
Shoestring Cr.	Alas. 344	(—)J-K-12
Short Cr.	Alas.	(—)H-15
Short Cr.	Alas. 88	(—)K-12
Short Cr.	Alas. K52	(—)O-16
Shosky Cr.	Alas.	(18)H-14
Shotgun Cr.	Alas. 446	(—)J-12
Shrode Cr.	Alas. 476	(—)J-12
Shuatochim Cr.	Alas.	(—)N-14
Shungnak Riv.	Alas.	(23)H-5-6
Sid Olds Riv.	Alas. 22K	(18)I-15
Siksikpuk Riv.	Alas.	(—)J-4
Siletz Riv.	Oreg.	(2)Q-28
Silta Karan Cr.	Alas.	(—)N-14
Siltcoss Cr.	Oreg.	(—)P-29
Silver Cr.	Oreg.	(—)P-Q-30
Silver Cr.	Oreg.	(4)Q-27-28
Silver Cr.	Wash.	(—)Q-24-25
Silverdale Cr.	Wash.	(—)Q-25
Silver Salmon Cr.	Alas. 68K	(18)I-15
Silver Salmon Cr. (Karluk Lake)	Alas.	(—)I-15
Similkameen Riv.	Wash.	(5)R-24, Q-R-23
Simmons Cr.	Oreg.	(—)Q-27
Simon Lake	Alas.	(—)J-12
Simpson Riv.	Alas. 26	(—)K-12
Sinuk Riv.	Alas.	(21)F-8
Sister Lake	Alas.	(—)M-N-15
Situk Riv.	Alas.	(14)M-13
Siuslaw Riv.	Oreg.	(2)P-Q-28-29
Siwash Cr.	Alas. 143	(—)K-11

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[19] Shown as "Status" on map.

[20] Shown as "Shishnikof" on map.

Continued ...

APPENDIX I. Continued.

Name	State		Location
Siwash Riv.	Alas.	264	(—) K-11
Six Riv.	Calif.		(—) P-Q-31
Sixes Riv.	Oreg.		(2) P-30
Sixmile Cr.	Alas.		(16B) J-12
Sixmile Lake	Alas.		(—) I-13
Skagit Riv.	Wash.		(3) Q-24
Skagway Riv.	Alas.		(13) N-13
Skilak Lake	Alas.		(16A) J-12
Skokomish Riv.	Wash.		(3) Q-25
Skookum Cr.	Wash.		(—) Q-24
Skookumchuck Riv.	Wash.		(3) Q-26
Skull Cr.	Alas.	K31	(7) O-17
Skwentna Riv.	Alas.		(17) I-J-11
Skykomish Riv.	Wash.		(3) Q-25
Slako Cr.	Alas.		(—) N-13
Slana Riv.	Alas.		(15) L-10
Slate Riv.	Alas.		(12) N-14
Slikok Cr.	Alas.		(—) J-12
Slug Riv.	Alas.		(20) G-14
Smith Cr.	Alas.	27	(—) K-12
Smith Cr.	Alas.	WC63	(—) N-16
Smith Cr.	Wash.		(—) Q-26
Smith Riv.	Calif.		(1) P-Q-31
Smith Riv.	Oreg.		(2) P-Q-29
Smoke Cr.	Alas.		(22) K-5
Smugglers Cr.	Alas.	K60	(7) O-N-17
Snake Cr.	Alas.	WR31	(8) N-16
Snake Riv.	Alas.		(—) F-8
Snake Riv.	Alas.		(20) H-13-14
Snake Riv.	Idaho, Oreg., Wash.		(4, 6) R-26-29
Snip Cr.	Alas.	K76	(—) O-17
Snohomish Riv.	Wash.		(3) Q-24-25
Snoqualmie Riv.	Wash.		(3) Q-25
Snow Cr.	Alas.		(16A) J-12
Snug Harbor Cr.	Alas.	682	(—) K-12
Sockeye Cr.	Alas.	687	(—) K-12
Sockeye Cr.	Alas.	E9D	(12) N-14
Sockeye Cr.	Alas.		(—) N-15
Sockeye Cr.	Alas.	K22	(—) O-17
Sockeye Cr.	Alas.	K14	(—) O-18
Soda Cr.	Alas.	WC32	(8) N-17
Soleduck Riv.	Wash.		(3) P-24-25
Soloman Cr.	Alas.	136	(—) K-11
Somme Lake	Alas.		(—) K-9
Soos Cr.	Wash.		(—) Q-25
Sophia Cr.	Alas.	E2	(10) N-15
Soquel Cr.	Calif.		(—) Q-36
South Cr. (Ugashik Lake)	Alas.		(—) H-15
South Cr.	Alas.	684	(—) K-12
South Cr.	Alas.		(—) N-18
South Riv.	Alas.		(21) G-9
South Alinchak Cr. (Kodiak)	Alas.		(—) I-15
South Arm Cr.	Alas.	98K	(18) I-15
Southeast Cr. (Gibraltar Lake)	Alas.		(—) I-13
Southeast Cr.	Alas.	WR26	(—) N-16
Southwest Woody Cr. (Nos. 1-4) (Iliamna Lake)	Alas.		(—) I-13
Spacious[21] Cr.	Alas.	K55	(7) O-17
Spasski Cr.	Alas.	I20	(11) N-14
Spectacle Cr.	Alas.		(—) I-13
Speel Riv.	Alas.		(12) N-14
Spiridon Riv.	Alas.	96K	(18) I-15
Spirit Lake	Wash.		(—) Q-26
Spiros Cr.	Alas.	614	(—) J-12
Spit Point Cr.	Alas.	K100	(7) O-17
Spring Cr. (Karluk Lake)	Alas.		(—) I-15
Spring Cr.	Alas.		(17) J-10
Spring Cr.	Alas.	20	(15*) K-12
Springs Riv.	Oreg.		(—) Q-28
Squaw Cr.	Alas.		(22) J-7
Squaw Cr.	Alas.		(16B) K-11
Squaw Cr.	Alas.	WR104	(8) N-16
Squire Cr.	Wash.		(—) Q-24
Squirrel Cr.	Alas.	447	(—) J-12
Squirrel Riv.	Alas.		(23) G-5
Squirrel Riv.	Alas.		(22) L-6-7
Squirrel Village Cr. (Iliamna Lake)	Alas.		(—) I-13
Staney Cr.	Alas.	WC52	(8) N-17
Stanislaus Riv.	Calif.		(1) Q-35
Stariski Cr.	Alas.		(16A) J-13
Station Lakes (Kodiak, Olga Bay)	Alas.		(—) I-15
Steamboat Cr.	Oreg.		(—) Q-29
Steel Cr.	Oreg.		(—) P-29
Steelhead Cr.	Alas.	WC43	(—) N-17
Steelhead Cr.	Alas.	K87A	(—) O-17
Stellar Cr.	Alas.	153	(—) K-11
Stephan Lake	Alas.		(17) J-10
Steve Cr. (Ugashik Lake)	Alas.		(—) H-15
Stevens Cr.	Wash.		(—) Q-25
Stewart Cr.	Alas.	K56	(—) O-17
Stikine Riv.	Alas.		(7) N-16
Stillaguamish Riv., and North and South Forks	Wash.		(3) Q-24
Stillman Cr.	Wash.		(—) Q-26
Stink Lake and Riv.	Alas.		(—) H-I-11
Stockdale Cr.	Alas.	752	(—) K-12
Stony Riv.	Alas.		(20*) H-I-11
Stormy Pt. Cr. and Lake	Alas.	71K	(18) I-15
Stracey's Cr. (Naknek Lake)	Alas.		(—) I-14
Straight Cr.	Alas.	E38	(9) N-16
Streets Lake Cr.	Alas.	WR41	(—) N-16
Striker Cr.	Alas.		(16C) I-13
Strom Cr.	Alas.	460	(15*) J-12
Sturgeon Riv.	Alas.	86K	(18) I-15
Stuyahok Riv.	Alas.		(21) G-10
Stuyarok[22] Riv.	Alas.		(20) H-13

[21] also called Wasta Creek.

[22] Shown as " Stuyahok " on map.

Continued ...

APPENDIX I. Continued.

Name	State	Location
Sucker Lake	Alas.	(17)J-11
Sucker Riv.	Alas.	(22)K-6
Sucker Bay Lake (Lake Clark)	Alas.	(—)I-12
Suiattle Cr.	Wash.	(—)Q-24
Sukhoi Lagoon	Alas.	(—)I-16
Sulatna Riv.	Alas.	(21)I-8
Sulphur Cr.	Idaho	(—)S-28
Sultan Riv.	Wash.	(—)Q-25
Sulua Cr.	Alas. 70K	(18)I-15
Summit Lake	Alas.	(15)K-9
Sunflower Cr.	Alas.	(—)J-10
Sunny Cr.	Alas. K156	(8)N-17
Sunny Cr.	Alas. WR18	(—)O-17
Sunny Riv.	Alas. 67a	(—)K-12
Sunshine Cr.	Alas.	(—)J-10-11
Surprise Cr.	Alas. 453	(—)J-12
Surprise Cr.	Alas. E3A	(10)N-15
Sushana Riv.	Alas.	(22)J-8-9
Susitna Riv.	Alas.	(16B, 17) J-10-11
Suslota Cr. and Lake	Alas.	(—)L-10
Sutter Cr.	Alas. WC62	(—)N-16
Swamp Cr. (Iliamna Lake)	Alas.	(—)I-13
Swamp Cr. (Naknek Lake)	Alas.	(—)I-14
Swamp Cr.	Alas. 739	(—)K-12
Swamp Cr.	Wash.	(—)Q-25
Swan Cr. and Lake	Alas.	(—)H-13
Swan Cr.	Alas.	(—)N-15
Swan Cr.	Alas. K99A	(—)O-17
Swan Lake	Alas.	(16B)J-17
Swan Cove Cr.	Alas. E13	(11)N-14-15
Swanson Cr.	Alas. 432	(—)J-12
Swanson Lagoon	Alas.	(—)G-17-18
Swanson Riv.	Alas.	(16B)J-12
Swansons Cr.	Alas. K70	(—)O-17
Swayee Cr.	Oreg.	(—)R-28
Swedania Cr.	Alas.	(—)G-17
Swede Lake	Alas.	(15)K-9-10
Sweetheart Cr.	Alas. E1C	(12)N-15
Swikshak Riv.	Alas. 107K	(18)I-14
Table Cr.	Oreg.	(—)P-28
Tahkenitch Cr.	Oreg.	(—)P-29
Tahuyeh Cr.	Wash.	(—)Q-25
Taiya Riv.	Alas.	(13)N-13
Takhin Riv.	Alas.	(13)N-13
Takhini Riv.	Alas.	(—)N-12
Taku Riv.	Alas.	(12)N-14
Talachulitna Lake and Riv.	Alas.	(17)J-11
Talarik Cr. (Iliamna Lake)	Alas.	(—)I-13
Talbiksok Riv.	Alas.	(21)G-11
Talkeen Cr.	Alas.	(—)N-16
Talkeetna Riv.	Alas.	(17)J-10
Tamar Cr.	Oreg.	(—)Q-27

Name	State	Location
Tamgas Cr. and Lake	Alas. K108	(7)O-17
Tana Riv.	Alas.	(—)L-11
Tanada Cr. and Lake	Alas.	(15)L-10
Tanalian Riv. (Lake Clark)	Alas.	(—)I-12
Tanana[28] Riv.	Alas.	(22)J-7-8, K-8
Taneum Cr.	Wash.	(—)Q-25
Tanis Lake and Riv.	Alas.	(14)M-13
Tatalina Riv.	Alas.	(22)J-7
Tatchum Riv.	Alas.	(—)N-11
Tatitlak Cr.	Alas. 102	(—)K-12
Tatlanika Cr.	Alas.	(22)J-8
Tatsatur Cr.	Alas.	(—)N-14
Tatshenskini Riv.	Alas.	(—)M-12
Tay Cr.	Alas.	(—)N-10
Tazimina Lake and Riv.	Alas.	(20)I-12-13
Tazlina Lake and Riv.	Alas.	(15)K-10-11
Teanaway Riv.	Wash.	(—)Q-25
Tebenkof Cr.	Alas. 450	(15*)J-12
Tedishoff Cr.	Alas. 101	(—)K-12
Teklanika Riv.	Alas.	(22)J-8
Telbay Riv.	Alas.	(—)L-11
Ten Mile Crs. and Lakes	Oreg.	(2)P-29
Ten Mile Cr.	Wash.	(—)Q-24
Ten Mile Riv.	Calif.	(1)Q-33
Ten Shot Cr. (Brooks Lake)	Alas.	(—)I-14
Terrell Cr.	Wash.	(—)Q-24
Terror Riv.	Alas. 101K	(18)I-15
Teshekpuk Lake	Alas.	(—)I-2
Teslin Riv.	Alas.	(—)N-11-12
Thayer Cr.	Alas. W49	(11)N-15
Theodore Riv.	Alas.	(16B)J-11
Thirtymile Cr.	Alas.	(—)N-13
Thomas Cr.	Oreg.	(4)Q-28
Thompson Cr.	Wash.	(—)Q-26
Thoms Cr.	Alas. WR27	(—)N-16
Thorne Riv.	Alas. K184	(8)N-17
Thornton Cr.	Wash.	(—)Q-25
Threemile Cr. and Lake	Alas.	(16B)J-11
Three Peak Riv.	Alas. W4	(11)N-15
Through Cr.	Alas.	(—)H-16
Thumb Cr. and Lake (Karluk Lake)	Alas.	(—)I-15
Thumb Cr.	Alas. 680	(—)K-12
Tiedeman Cr.	Alas. 501	(—)J-12
Tiekel Riv.	Alas.	(15)K-11
Tieton Riv.	Wash.	(—)Q-26
Tiger Cr.	Alas. 616	(—)J-12
Tikchik Lake and Riv.	Alas.	(20)H-12
Tillamook Riv.	Oreg.	(—)Q-27
Tiller Cr.	Oreg.	(—)Q-30
Tilton Riv.	Wash.	(—)Q-26
Titaluk Riv.	Alas.	(23*)I-3
Titna Riv.	Alas.	(—)I-8

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[28] Shown as "Tenana" on map.

Continued …

Appendix I. Continued.

Name	State	Location
Tlikakila Riv.	Alas.	(20) I-12
Togiak Cr. and Lake	Alas.	(20) H-13
Togiak Riv.	Alas.	(20) G-H-13
Tokchitna Riv.	Alas.	(—) J-10
Tokeen Cr.	Alas. WC67	(—) N-16
Toklat Riv.	Alas.	(22) J-8
Tokul Cr.	Wash.	(—) Q-25
Tokum Lake	Alas.	(—) K-12
Tolovana Riv.	Alas.	(22) J-7-8
Tolt Riv.	Wash.	(—) Q-25
Tom Cr.	Alas. K153	(—) N-17
Tom Cr.	Alas. WR9	(7) O-16
Tombstone Riv.	Alas. K3	(7) O-17
Tomkok Cr. (Iliamna Lake)	Alas.	(—) I-13
Tommy Riv. (Iliamna Lake)	Alas.	(—) I-13
Tom's Cr.	Alas. 61K	(18) I-16
Tom's Cr.	Alas.	(—) N-16
Tonsina Lake and Riv.	Alas.	(—) K-11
Tooliok Riv.	Alas.	(23*) J-3
Topagoruk Riv.	Alas.	(23*) I-2
Totatlanika Cr.	Alas.	(22) J-8
Totem Cr.	Alas. WR63	(10) N-16
Totemoff Cr.	Alas. 621	(—) J-12
Touchet Riv.	Wash.	(4) R-26
Toutle Riv.	Wash.	(4) Q-26
Tozitna Riv.	Alas.	(22) I-7
Trail Cr.	Alas.	(23) G-4
Trail Cr.	Alas.	(—) H-12
Trail Cr.	Alas.	(—) H-13
Trail Cr.	Alas.	(16A) J-12
Trail Cr.	Alas. 687a	(—) K-12
Trail Cr.	Oreg.	(—) Q-30
Trail Lake and Riv.	Alas.	(16A) J-12
Traitors Cr.	Alas. K84	(7) O-17
Trap Cr.	Alas. 701	(—) K-13
Trask Riv.	Oreg.	(2) Q-27
Triangle Cr. (Nos. 1-3) (Iliamna Lake)	Alas.	(—) I-13
Trinity Cr.	Alas. 443	(—) J-12
Trinity Lake	Alas.	(—) J-11
Trinity Riv.	Calif.	(1) Q-31-32
Triple Cr.	Alas. 303	(—) K-12
Trocadero Cr.	Alas. WC35	(8) N-17
Troublesome Riv.	Alas.	(22) J-7
Trout Cr. (Gibraltar Lake)	Alas.	(—) I-13
Trout Cr.	Alas. WR89	(8) N-16
Trout Cr.	Alas. K113	(—) O-17
Trout Cr.	Wash.	(—) Q-27
Tsirku Riv.	Alas.	(13) M-N-13
Tsiu Riv.	Alas.	(15) L-12
Tualatin Riv.	Oreg.	(4) Q-27
Tucannon Riv.	Wash.	(6) R-26
Tulsona Riv.	Alas.	(—) K-10
Tumwater Cr.	Wash.	(—) Q-24
Tundra Cr.	Alas. 73	(—) K-12
Tunehean Cr.	Alas. WR67	(10) N-16
Tuolumne Riv.	Calif.	(1) Q-35
Turn Cr.	Alas. 486	(—) J-12
Turner Cr.	Alas. 114	(—) K-12
Tustumena Lake	Alas.	(16A) J-12
Tutuksuk Riv.	Alas.	(23) H-5
Tuxedni Bay streams	Alas.	(16C) I-12
Twelvemile Cr.	Alas. E31C	(—) N-15
Twelvemile Cr.	Alas. K175	(8) N-17
Twentymile Cr.	Alas.	(16B) J-12
Twentytwo (22) Cr. (Lake Clark)	Alas.	(—) I-12
Twin Falls Cr.	Alas. 152	(—) K-11
Twin Lake Cr.	Alas. 19	(—) K-12
Twisp Riv.	Wash.	(5) Q-24
Two Island Cove Cr.	Alas. W44A	(—) N-14
Two Moon Cr.	Alas. 72	(—) K-12
Tyonek Cr.	Alas.	(16B) J-11
Ualik Lake	Alas.	(20) H-13
Udall Cr.	Alas. 770	(—) K-12
Ugaklik Cr.	Alas.	(20*) G-12-13
Ugalik Riv.	Alas.	(21) G-8
Uganik Lake and Riv.	Alas. 100K	(18) I-15
Ugashik Cr. (Ugashik Lake)	Alas.	(—) H-15
Ugashik Lake	Alas.	(18) H-15
Ugashik Riv. (Ugashik Bay)	Alas.	(18) H-15
Ukak Cr. (Naknek Lake)	Alas.	(—) I-14
Umatilla Riv.	Oreg.	(4) R-27
Umpqua Riv., and North and South Forks	Oreg.	(2) Q-29
Unakwik Cr.	Alas. 265	(—) K-12
Unalakleet Riv.	Alas.	(21) G-8-9
Unalaska Island streams	Alas.	(25) F-19
Unalaska Lake	Alas.	(25) F-19
Unaluk Riv.	Alas.	(20) G-14
Unga Island streams	Alas.	(—) G-17
Union Riv.	Wash.	(—) Q-25
Unuk Riv.	Alas. K48	(7) O-16
Up-a-hill Cr. (Naknek Lake)	Alas.	(—) H-14
Up-a-tree Cr. (Brooks Lake)	Alas.	(18) I-14
Upnuk Lake	Alas.	(20) H-12
Upper Station Cr.	Alas. 69K	(18) I-15
Upper Talarik Cr. (Iliamna Lake)	Alas.	(—) I-13
Urilia Bay creeks	Alas.	(19) F-18
Useless Cr.	Alas. 209	(—) K-12
Ustay Lake and Riv.	Alas.	(14) M-13
Usuktuk Riv.	Alas.	(23*) H-3
Utukok Riv.	Alas.	(23*) G-2-3
Uukpalik Cr.	Alas.	(—) H-12
Uyak Riv.	Alas. 90K	(18) I-15
Vallenar Cr.	Alas. K116	(—) O-17

Continued …

APPENDIX I. Continued.

Name	State	Location
Valley Cr.	Idaho	(—)S-28
Valley Ford Cr.	Calif.	(1)Q-34
Vance Cr.	Wash.	(—)Q-25
Van Duzen Riv.	Calif.	(1)P-Q-32
Vanishing Cr.	Alas. 216	(—)K-12
Van Sant Cr.	Alas. WC72	(—)N-16
Ventna Riv.	Alas.	(17)J-10-11
Very Cr.	Alas. K18	(7)O-17
Vesta Cr.	Alas. WC22	(—)N-18
Vesta Cr.	Wash.	(—)Q-26
Village Cr.	Alas. 307	(—)J-12
Village Cr.	Alas. 109K	(18)I-14
Vixen Cr.	Alas. WR22	(7)N-17
Vixen Cr. (Vixen Bay)	Alas. K20	(7)O-17
Vlasoff Cr.	Alas. 129	(—)K-11
Volcano Cr. (Mother Goose Lake)	Alas.	(—)H-15
Volkmar Riv.	Alas.	(22)K-8
Waddell[24] Cr.	Calif.	(1)Q-35
Walker Cr.	Alas. K43	(7)O-17
Walku Cr.	Calif.	(—)Q-31
Wallace Cr.	Wash.	(—)Q-25
Walla Walla Riv.	Wash.	(4)R-26-27
Wallowa Riv.	Oreg.	(6)R-27
Ward Cr.	Alas. W46	(11)N-15
Ward Cr.	Alas. K90	(—)O-17
Ward Cr.	Wash.	(—)Q-26
Washington Cr.	Alas.	(22)J-7
Washington Lake	Wash.	(—)Q-25
Washougal Riv.	Wash.	(4)Q-27
Wasilla Lake	Alas.	(16B)J-11
Wasta Cr. (see Spacious Cr.)		
Waterfall Cr.	Alas. 263	(—)K-12
Waterfall Cr.	Alas. WC19	(8)N-17
Weary Riv.	Alas.	(20)H-13
Weiser Riv.	Idaho	(6)R-28
Wenaha Riv.	Oreg.	(6)R-27
Wenatchee Lake and Riv.	Wash.	(5)Q-25
West Cr. (Brooks Lake)	Alas.	(—)I-14
West Cr.	Alas. 28K	(18)I-15
West Alinchak Cr.	Alas. 128K	(18)I-15
West Finger Cr.	Alas. 485	(—)J-12
West Glacier Cr.	Alas.	(16C)I-13
West LaGorce Cr. (Naknek Lake)	Alas.	(—)I-14
West Twin Cr.	Alas. 293	(15*)K-12
Whakatna Riv.	Alas.	(21)G-9
Whale Cr.	Alas. 636	(—)J-12
Whale Pass	Alas. WR105	(8)N-16
Whalen Cr.	Alas. 80	(15*)K-12
Wheeler Cr.	Alas. W45	(11)N-14
Whisky Cr.	Alas. 853	(—)K-12
Whisky Lake	Alas.	(—)J-10-11
White Cr.	Oreg.	(—)Q-27
White Riv.	Alas. K94	(7)O-17
White Riv.	Wash.	(3)Q-25
Whitechuck Cr.	Wash.	(—)Q-24
Whitehouse Cr.	Calif.	(—)Q-35
Whiting Riv.	Alas.	(12)N-14
Whittier Cr.	Alas. 441	(—)J-12
Wickett Cr.	Alas. 469	(—)J-12
Wide Bay Cr.	Alas.	(—)H-15
Wilby Cr.	Alas. 744	(—)K-12
Wild Cr.	Alas. 26-1K	(18)I-15
Wild Cr.	Alas. 745	(15*)K-12
Wildcat Cr.	Wash.	(—)Q-25
Wilkeson Cr.	Wash.	(—)Q-25
Willamette Riv.	Oreg.	(4)Q-27-28
Willapa Riv.	Wash.	(3)Q-26
Willard Cr.	Alas. K11	(—)O-18
Williams Cr.	Oreg.	(—)Q-30
Willow Cr.	Alas.	(17)J-11
Wills Riv.	Alas. 234	(—)K-11
Wilson Cr.	Wash.	(—)Q-26
Wilson Lake and Riv.	Alas. K34	(7)O-17
Wilson Riv., East Fork	Alas. K34-1	(7)O-17
Wilson Riv.	Oreg.	(2)Q-27
Wind Cr.	Alas.	(22)K-5
Wind Riv. (Wood Riv.)	Alas.	(—)H-13
Wind Riv.	Wash.	(4)Q-27
Windchuck Cr.	Oreg.	(—)P-30
Windy Bay streams	Alas.	(—)J-13
Winstanley Cr.	Alas. K37	(7)O-17
Wishkah Riv.	Wash.	(3)Q-25-26
Wolf Cr.	Alas. WC59	(—)N-16
Wolf Cr.	Alas. K64	(7)N-17
Wolf Cr.	Alas. K88	(—)O-17
Wolverine Cr.	Alas. 631	(16B)J-11
Wolverine Cr.	Alas. K34A	(—)O-17
Wood Riv. and Lakes (see Aleknagik, Beverley, Kulik, Nerka and Little Togiak)	Alas.	(20)H-13
Wood Riv.	Alas.	(22)J-8
Woodward Cr.	Oreg.	(—)P-30
Woodward Cr.	Wash.	(—)Q-25
Wooley Cr.	Calif.	(1)Q-31
Wright Cr.	Alas.	(—)N-14
Wulik Riv.	Alas.	(23)F-G-5
Wynoochee Riv.	Wash.	(3)Q-25-26
"X" Lake	Alas.	(—)N-14
"Y" Cr. and Lake	Alas.	(—)N-14
Yachats Cr.	Oreg.	(—)Q-28
Yakataga Cr.	Alas.	(—)L-12
Yakima Riv.	Wash.	(5)Q-25, Q-R-26
Yaktze Riv.	Alas.	(—)L-13
Yamhill Riv.	Oreg.	(4)Q-27
Yankee Cr.	Idaho	(—)S-28
Yaquina Riv.	Oreg.	(2)P-Q-28

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[24] Shown as "Waddel" on map.

Continued ...

Appendix I. Continued.

Name	State	Location
Yehring Cr.	Alas. E9E	(12) N-14
Yentna Riv.	Alas.	(16B) J-11
Yes Riv.	Alas. K54	(7) O-17
Young Cr.	Alas. K179	(—) N-17
Youngs Cr. (Iliamna Lake)	Alas.	(—) I-13
Youngs Riv.	Oreg.	(4) Q-26-27
Yuba Riv.	Calif.	(1) Q-33
Yuko Riv.	Alas.	(21) G-9
Yukon Riv.	Alas.	(21) F-G-9-10
"Z" Riv.	Alas.	(—) N-O-14
Zachar Cr.	Alas. 95K	(18) I-15
Zachar Riv.	Alas. 94K	(18) I-15
Zaikof Cr.	Alas. 769	(—) K-12
Zillesenoff Cr.	Alas. 851	(—) K-12
Zitziana Riv.	Alas.	(22) J-8

APPENDIX II

NUMERICAL INDEX TO ALASKAN STREAMS WITH CROSS-INDEX TO NAMES

"Location" has the same reference as in Appendix I. Numbers were assigned for our indexing and mapping purposes; U.S. Fish and Wildlife numbering was used in some southeastern Alaskan areas. All the streams listed here are not identified on our maps.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
Alaska Peninsula, South Side (Excluding Shelikof Strait)		
4	(18) H-15–16	
4	(19) G-17	
5	(18) H-15–16	
7	(18) H-15	
8	(18) H-15	Fleming Cr.
9	(18, 19) H-16	
10	(18, 19) H-16	
11	(18, 19) H-16	
12	(18) H-15	
12	(18) H-16	
13	(18) H-16	
14	(18) H-16	
14a	(18) H-16	
15	(18) H-16	
18a	(18) H-16	
18b	(18) H-16	
20	(19) G-17	
20	(19) H-16	
21	(19) G-17	
22	(19) G-17	
22	(19) H-16	
23	(—) G-17	
24	(19) G-17	
26	(19) G-17	
26	(19) H-16	
27	(19) G-17	Canoe Riv.
28	(19) H-16	
30	(19) G-17	Middle Cr.
31	(19) G-17	
32	(19) G-17	
33	(19) G-17	Mino Cr.
33a[1]	(19) G-17	
33b[1]	(19) G-17	
33c[1]	(19) G-17	
40	(19) G-17	
41	(19) G-17	
42	(19) G-17	
43	(19) G-17	
44	(19) G-17	
45	(19) G-17	
46	(19) G-17	
47	(19) G-17	
48	(19) H-17	
49	(19) H-17	
50	(19) H-17	
51	(19) H-17	
52	(19) H-17	
54	(19) H-17	
55	(19) H-17	
56	(19) H-17	
57	(19) H-17	
57a	(19) H-17	
58	(19) H-16	
Kodiak Island (Including North Shore of Shelikof Strait)		
1K	(18) I-14	Malina Cr.
2K	(18) I-14	Paramanof Lagoon Cr.
3K	(18) I-14	
4K	(18) I-14	
5K	(18) I-14	Perenosa Cr.
6K	(18) I-14	Pauls Lake Cr.
7K	(18) I-14	Saposa Cr.
7K-1	(18) I-14	Little Kitoi Lake Cr.
8K	(18) I-14	Big Kitoi Lake Cr.
9K	(18) I-14	
10K	(18) I-14	Danger Cr.
12K	(18) I-14	Marka Cr.
13K	(18) I-14	
14K	(18) I-14	Afognak Riv.
15K	(18) I-15	Monashka Cr.
16K	(18) I-15	Pillar Cr.
17K	(18) I-15	Buskin Cr.
18K	(18) I-15	Sargent Cr.
19K	(18) I-15	Salonie Riv.
20K	(18) I-15	American Riv.
21K	(18) I-15	Kalsin Cr.
22K	(18) I-15	Sid Olds Riv.
23K	(18) I-15	Sacramento Riv.
24K	(18) I-15	Pasagshak Cr.
25K	(18) I-15	Portage Bay Cr.
26K	(18) I-15	Saltery Cr.
26–1K	(18) I-15	Wild Cr.
27K	(18) I-15	Hidden Basin Cr.
28K	(18) I-15	West Cr.
29K	(18) I-15	Long Arm Cr.
30K	(18) I-15	Gull Point Cr.
31K	(18) I-15	Eagle Harbor Cr.

[1] Shown as "a", "b", "c", on map.

Continued ...

Appendix II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
40K	(18) I-15	
41K	(18) I-15	Dog Bay Cr.
42K	(18) I-15	Shearwater Cr.
43K	(18) I-15	
44K	(18) I-15	Kiliuda Cr.
45K	(18) I-15	Midway Bay Riv.
46K	(18) I-15	Barling Riv.
50K	(18) I-16	Jean Cr.
51K	(18) I-15	Kaiugnak Cr.
60K	(18) I-15–16	
61K	(18) I-16	Tom's Cr.
62K	(18) I-16	Kaguyak Cr.
65K	(18) I-16	Seven Rivers
66K	(18) I-16	Humpy Cr.
67K	(18) I-15	Russian River
68K	(18) I-16	Silver Salmon Cr.
69K	(18) I-15	Upper Station Cr.
70K	(18) I-16	Sulua Cr.
71K	(18) I-16	Stormy Pt. Cr.
72K	(18) I-16	
73K	(18) I-16	
74K	(18) I-15	Deadman Riv.
75K	(18) I-15	Narrows Cr.
76K	(18) I-15	Horse Marine Cr.
77K	(18) I-15	Dog Salmon Cr.
78K	(18) I-15	Cannery Station Cr.
79K	(18) I-15	Olga Cr.
83K	(18) I-15	Red Riv.
85K	(18) I-15	Halibut Bay Cr.
86K	(18) I-15	Sturgeon Riv.
88K	(18) I-15	Karluk Riv.
90K	(18) I-15	Uyak Riv.
91K	(18) I-15	
93K	(18) I-15	Brown's Lagoon Cr.
94K	(18) I-15	Zachar Riv.
95K	(18) I-15	Zachar Cr.
96K	(18) I-15	Spiridon Riv.
97K	(18) I-15	Little Riv.
98K	(18) I-15	South Arm Cr.
99K	(18) I-15	
100K	(18) I-15	Uganik Riv.
101K	(18) I-15	Terror Riv.
102K	(18) I-15	Baumanns Cr.
103K	(18) I-15	Barabara Cove Cr.
104K	(18) I-15	Kizhuyak Cr.
105K	(18) I-15	Elbow Cr.
106K	(18) I-15	Anton Larson Cr.
107K	(18) I-14	Swikshak Riv.
108K	(18) I-14	Big Riv.
109K	(18) I-14	Village Cr.
110K	(18) I-14	Ninigiak Riv.
111K	(18) I-14	
112K	(18) I-14	Hallo Cr.
113K	(18) I-14	Kukak Cr.
116K	(18) I-14	Kaflia Cr.
119K	(18) I-14	Dakavak Cr.
125K	(18) I-15	Kashvik Cr.
126K	(18) I-15	Bare Cr.
127K	(18) I-15	North Alinchak Cr.
128K	(18) I-15	West Alinchak Cr.
132K	(18) I-15	
Prince William Sound		
1	(15*) K-12	
2	(—) K-12	Hartney Cr.
3	(—) K-12	Nicolet Cr.
4	(—) K-12	Heney Cr.
5	(—) K-12	Eccles Cr.
7	(—) K-12	Ocean Dock Cr.
9	(—) K-12	Crater Lake Cr.
10	(—) K-12	
11	(—) K-12	Humpy Cr.
12	(—) K-12	Shepard Cr.
13	(—) K-12	
14	(—) K-12	
15	(15*) K-12	Nelson Cr.
16	(—) K-12	Rude Riv.
17	(—) K-12	
18	(—) K-12	Hidden Cr.
19	(—) K-12	Twin Lake Cr.
20	(15*) K-12	Spring Cr.
21	(—) K-12	Rogue Cr.
22	(—) K-12	
23	(—) K-12	Chase Riv.
24	(—) K-12	
25	(15*) K-12	
26	(—) K-12	Simpson Riv.
27	(—) K-12	Smith Cr.
28	(—) K-12	Durkee Cr.
29	(—) K-12	
30	(—) K-12	
31	(—) K-12	
32	(—) K-12	
33	(—) K-12	
34	(—) K-12	
35	(15*) K-12	Koppen Cr.
36	(—) K-12	Sheep Riv.
37	(—) K-12	Allen Cr.
38	(—) K-12	
39	(—) K-12	
40	(15*) K-12	Gravina Point Cr.
41	(—) K-12	Pass Cr.
42	(—) K-12	
43	(—) K-12	
44	(—) K-12	
45	(—) K-12	Plateau Cr.
46	(—) K-12	Comfort Cr.
47	(—) K-12	
48	(—) K-12	Beartrap Riv.
49	(—) K-12	Cateract Cr.
50	(15*) K-12	Gravina Riv.

Continued ...

APPENDIX II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any	No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
51	(—)K-12	Olsen Cr.	105	(—)K-12	Bridge Cr.
52	(—)K-12	Control Cr.	106	(—)K-12	Gladhough Cr.
53	(—)K-12		107	(—)K-12	Black Cr.
54	(—)K-12	Carlsen Cr.	108	(15*)K-12	Bligh Cr.
55	(—)K-12		109	(—)K-12	Ranch Cr.
56	(—)K-12	Saint Matthews Cr.	110	(—)K-12	Fox Cr.
57	(—)K-12		111	(—)K-12	Cloudman Cr.
58	(—)K-12		112	(—)K-12	Katelnikoff Cr.
59	(—)K-12		113	(15*)K-12	Bushby Cr.
60	(—)K-12		114	(—)K-12	Turner Cr.
61	(—)K-12		115	(15*)K-12	Millard Cr.
62	(—)K-12		116	(—)K-12	Duck Riv.
63	(—)K-12		117	(—)K-12	Indian Cr.
64	(—)K-12		118	(—)K-12	Krause Cr.
65	(15*)K-12	Coho Cr.	119	(—)K-12	Johnson Cove Cr.
66	(—)K-12		120	(—)K-12	Donaldson Cr.
67	(—)K-12	Knowls Cr.	121	(—)K-11	Levshakoff Cr.
67a	(—)K-12	Sunny Riv.	122	(—)K-11	
68	(—)K-12		123	(—)K-12	Gregorioff Cr.
69	(—)K-12		124	(—)K-11-12	
70	(—)K-12		125	(15*)K-12	
71	(—)K-12		126	(—)K-12	
72	(—)K-12	Two Moon Cr.	127	(—)K-11-12	Naomoff Cr.
73	(—)K-12	Tundra Cr.	128	(—)K-11	
74	(—)K-12		129	(—)K-11	Vlasoff Cr.
75	(—)K-12		130	(15*)K-11	Confusion Cr.
76	(—)K-12	Irish Cr.	131	(—)K-11	
77	(—)K-12		132	(—)K-11	
78	(—)K-12		133	(—)K-11	Sawmill Cr.
79	(—)K-12		134	(—)K-11	Dayville Cr.
80	(15*)K-12	Whalen Cr.	135	(15*)K-11	Allison Cr.
81	(—)K-12		136	(—)K-11	Soloman Cr.
82	(—)K-12		137	(15*)K-11	Lowe Riv.
83	(—)K-12	Keta Cr.	138	(—)K-11	
84	(—)K-12		139	(—)K-11	
85	(15*)K-12		140	(15*)K-11	
86	(—)K-12	Fidalgo Riv.	141	(—)K-11	
87	(—)K-12		142	(—)K-11	
88	(—)K-12	Short Cr.	143	(—)K-11	Siwash Cr.
89	(—)K-12	Fish Cr.	144	(—)K-11	
90	(15*)K-12		145	(15*)K-11	Crooked Cr.
91	(—)K-12		146	(—)K-11	
92	(—)K-12	Shale Cr.	147	(—)K-11	Mineral Cr.
93	(—)K-12	Kirkwood Cr.	148	(—)K-11	Gilmour Cr.
94	(—)K-12	Rock Cr.	149	(—)K-11	Gold Cr.
95	(—)K-12	Cutthroat Cr.	150	(15*)K-11	Kaydas Cr.
96	(—)K-12	Banzer Cr.	151	(—)K-11	
97	(—)K-12		152	(—)K-11	Twin Falls Cr.
98	(—)K-12	Rainbow Cr.	153	(—)K-11	Stellar Cr.
99	(—)K-12	Lagoon Cr.	154	(—)K-11	
100	(—)K-12	Borodkin Cr.	155	(—)K-12	
101	(—)K-12	Tedishoff Cr.	201	(—)K-12	Emerald Cr.
102	(—)K-12	Tatitlak Cr.	202	(—)K-12	
103	(—)K-12	Brown Cr.	203	(—)K-12	
104	(—)K-12	Boardwalk Cr.	204	(—)K-12	

Continued ...

APPENDIX II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
205	(15*) K-12	Columbia Cr.
206	(—) K-11	
207	(—) K-11	
208	(—) K-12	
209	(—) K-12	Useless Cr.
210	(15*) K-12	
211	(—) K-12	
212	(—) K-12	
213	(—) K-11	Bench Mark Cr.
214	(—) K-12	Long Cr.
215	(15*) K-12	
216	(—) K-12	Vanishing Cr.
217	(—) K-12	
218	(—) K-12	Billies Hole
219	(—) K-12	
220	(—) K-12	
221	(—) K-12	Eickelberg Cr.
222	(—) K-12	Sere Cr.
223	(—) K-12	
224	(—) K-12	Backyard Cr.
225	(—) K-12	Fletcher Cr.
226	(—) K-12	
227	(—) K-12	Granite Cr.
228	(—) K-12	
229	(—) K-12	
230	(15*) K-12	
231	(—) K-12	
232	(—) K-12	
233	(—) K-11	
234	(—) K-11	Wills Riv.
235	(15*) K-11	
236	(—) K-11	
237	(—) K-12	
238	(—) K-12	
239	(—) K-12	
240	(—) K-12	
241	(—) K-11	Cannery Cr.
242	(—) K-11	Cow Pen Cr.
243	(—) K-11	
244	(—) K-11	Miner's Riv.
245	(15*) K-11	
246	(—) K-11	
247	(—) K-11	
248	(—) K-11	
249	(—) K-11	
250	(15*) K-11	
251	(—) K-11	
252	(—) K-11	
253	(—) K-11	
254	(—) K-11	
255	(15*) K-11	
256	(—) K-11	
257	(—) K-11	
258	(—) K-11	Jonah Cr.
259	(—) K-11	
260	(15*) K-12	
261	(—) K-12	
262	(—) K-12	
263	(—) K-12	Waterfall Cr.
264	(—) K-11	Siwash Riv.
265	(—) K-12	Unakwik Cr.
266	(—) K-12	
267	(—) K-12	
268	(—) K-12	
269	(—) K-12	Kiniklik Cr.
270	(15*) K-12	Pellew Cr.
271	(—) K-12	Anchorage Cr.
272	(—) K-12	
273	(—) K-12	Schoppe Cr.
274	(—) K-12	
275	(15*) K-12	
276	(—) K-12	Black Bear Cr.
277	(—) K-12	
278	(—) K-12	
279	(—) K-12	Canyon Cr.
280	(15*) K-12	
281	(—) K-12	Eaglek Riv.
282	(—) K-12	
283	(—) K-12	
284	(—) K-12	
285	(15*) K-12	Cascade Riv.
286	(—) K-12	
287	(—) K-12	
288	(—) K-12	
289	(—) K-12	Derickson Cr.
290	(—) K-12	
291	(—) K-12	
292	(—) K-12	Papoose Cr.
293	(15*) K-12	West Twin Cr.
294	(15*) K-12	East Twin Cr.
295	(15*) K-12	Lambert Lagoon
296	(15*) K-12	Naked Cr.
297	(—) K-12	Clock Cr.
298	(15*) K-12	Finski Cr.
299	(15*) K-12	Campbell Cr.
299a	(—) K-12	Cedar Cr.
300	(—) K-12	Red Cr.
301	(—) K-12	
302	(—) K-12	
303	(—) K-12	Triple Cr.
304	(—) K-12	
305	(—) J-12	
306	(—) J-12	
307	(—) J-12	Village Cr.
308	(—) J-12	
309	(—) J-12	
310	(15*) J-K-12	Golden Lagoon
311	(—) K-12	Golden Riv.
312	(—) K-12	
313	(—) K-12	

Continued ...

APPENDIX II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
314	(—)K-11	Avery Riv.
315	(15*)K-12	
316	(—)K-12	
317	(—)K-11	
318	(—)K-11	Crescent Riv.
319	(—)K-11	
320	(15*)K-11	Amherst Riv.
321	(—)K-11	Lafayette Riv.
322	(—)K-11	Coghill Riv.
323	(—)K-11	
324	(—)K-11	
325	(15*)K-11	
326[2]	(15*)K-11	
327	(—)K-11	Holyoke Cr.
328	(—) J-12	
329	(—) J-12	
330	(15*) J-12	
331	(—) J-12	
332	(—) J-12	
333	(—) J-12	
334	(—) J-12	
335	(15*) J-12	
336	(—) J-12	Esther Riv.
337	(—) J-12	
338	(—) J-12	
339	(—) J-12	
340	(—)K-12	
341	(—)K-12	
342	(—)K-12	
343	(—) J-12	
344	(—) J-K-12	Shoestring Cr.
345	(—)K-12	
400	(—) J-11	
401	(—) J-11	
402	(—) J-11	Mosquito Cr.
403	(—) J-11	
404	(—) J-11	
405	(15*) J-11	
406	(—) J-11	
407	(—) J-11	
408	(—) J-11	
409	(—) J-11	
410	(15*) J-11	
411	(—) J-11	
412	(—) J-11	
413	(—) J-12	
414	(—) J-12	Harrison Cr.
415	(—) J-12	
416	(—) J-12	
417	(—) J-12	Hobo Cr.
418	(—) J-12	
419	(—) J-12	
420	(15*) J-12	
421	(—) J-12	Mill Cr.
422	(—) J-12	Bettles Riv.
423	(—) J-12	
424	(—) J-12	
425	(15*) J-12	Hummer Cr.
426	(—) J-12	
427	(—) J-12	
428	(—) J-12	Pirate Cr.
429	(—) J-12	
430	(15*) J-12	Meacham Cr.
431	(—) J-12	Pigot Riv.
432	(—) J-12	Swanson Cr.
433	(—) J-12	
434	(—) J-12	Entry Cove Cr.
435	(—) J-12	Logging Camp Cr.
436	(—) J-12	Poe Riv.
437	(—) J-12	
438	(—) J-12	Billings Riv.
439	(—) J-12	
440	(15*) J-12	Shakespeare Cr.
441	(—) J-12	Whittier Cr.
442	(—) J-12	Cove Cr.
443	(—) J-12	Trinity Cr.
444	(—) J-12	
445	(—) J-12	
446	(—) J-12	Shotgun Cr.
447	(—) J-12	Squirrel Cr.
448	(—) J-12	
449	(—) J-12	
450	(15*) J-12	Tebenkof Cr.
451	(—) J-12	Blackstone Cr.
452	(—) J-12	
453	(—) J-12	Surprise Cr.
454	(—) J-12	Halferty Cr.
455	(15*) J-12	Paulson Cr.
456	(—) J-12	
457	(—) J-12	
458	(—) J-12	Parks Cr.
459	(—) J-12	Rainy Cr.
460	(15*) J-12	Strom Cr.
461	(—) J-12	Cochrane Cr.
462	(—) J-12	
463	(—) J-12	
464	(—) J-12	Gilbert Cr.
465	(—) J-12	Robbers Cr.
466	(—) J-12	
467	(—) J-12	
468	(—) J-12	
469	(—) J-12	Wickett Cr.
470	(15*) J-12	
471	(—) J-12	Narrows Cr.
472	(—) J-12	
473	(—) J-12	
474	(—) J-12	
475	(—) J-12	
476	(—) J-12	Shrode Cr.

Continued …

[2] Shown as "328" on map.

APPENDIX II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
477	(—) J-12	
478	(15*) J-12	
479	(—) J-12	Culross Cr.
480	(—) J-12	Mink Cr.
481	(—) J-12	
482	(—) J-12	
483	(—) J-12	
484	(—) J-12	East Finger Cr.
485	(—) J-12	West Finger Cr.
486	(—) J-12	Turn Cr.
487	(—) J-12	Kings Riv.
488	(—) J-12	Nellie Juan Riv.
489	(—) J-12	
490	(15*) J-12	Greystone Cr.
491	(—) J-12	Deep Water Cr.
492	(—) J-12	
493	(—) J-12	Most Cr.
494	(—) J-12	
495	(15*) J-12	Chimevisky Lagoon
496	(—) J-12	
497	(—) J-12	
498	(—) J-12	McClure Cr.
499	(—) J-12	Shipyard Cr.
500	(15*) J-12	Port Nellie Juan Cr.
501	(—) J-12	Tiedeman Cr.
502	(—) J-12	Discher Cr.
503	(—) J-12	Main Riv.
504	(—) J-12	Comstock Cr.
505	(15*) J-12	Hanning Cr.
506	(—) J-K-12	Loomis Cr.
507	(—) J-12	Gumboot Cr.
508	(—) J-12	
509	(—) J-12	
510	(—) J-12	Eleshansky Cr.
511	(—) J-12	Eshamy Riv.
512	(—) J-12	
513	(—) J-12	
514	(—) J-12	
515	(15*) K-12	
516	(—) J-12	Clemence Cr.
600	(15*) J-12	
601	(—) J-11	Paddy Cr.
602	(—) J-12	Nacktan Cr.
603	(—) J-12	Ewan Cr.
604	(—) J-12	Erb Cr.
605	(—) J-12	
606	(—) J-12	
607	(—) J-12	
608	(—) J-12	Jack Pot Riv.
609	(—) J-12	
610	(15*) J-12	Kompkoff Riv.
611	(—) J-12	
612	(—) J-12	
613	(—) J-12	Jackson Cr.
614	(—) J-12	Spiros Cr.
615	(—) J-12	
616	(—) J-12	Tiger Cr.
617	(—) J-12	Princeton Cr.
618	(—) J-12	Junction Cr.
619	(—) J-12	
620	(—) J-12	
621	(—) J-12	Totemoff Cr.
622	(—) J-12	
623	(—) J-12	Brizgaloff Cr.
624	(—) J-12	
625	(—) J-12	Kononoff Cr.
626	(—) J-12	
627	(—) J-12	Kake Cr.
628	(—) J-12	Chenega Cr.
629	(—) J-12	
630	(—) J-12	Bainbridge Cr.
631	(—) J-12	
632	(—) J-12	Claw Cr.
623	(—) J-12	Pablo Cr.
634	(—) J-12	
635	(—) J-12	
636	(—) J-12	Whale Cr.
637	(—) J-12	Countess Cr.
638	(—) J-12	
639	(—) J-12	Passage Cr.
640	(—) J-12	
641	(—) J-12	
642	(—) J-12	
643	(—) J-12	
644	(—) J-13	
645	(15*) J-13	
646	(—) J-13	Puget Lake
647	(—) J-12	
648	(—) J-12	
649	(—) J-12	Puget Riv.
650	(15*) J-13	
651	(—) J-12	Doubtful Cr.
652	(—) J-12	
653	(—) J-12	Hogg Cr.
654	(—) J-12	
655	(—) J-12	Johnson Cr.
656	(—) J-12	Halverson Cr.
657	(—) J-12	
658	(—) J-12	
659	(—) J-12	
660	(—) K-12	
661	(—) J-12	Calvert Cr.
662	(—) K-12	
663	(—) K-12	Shelter Cr.
664	(—) K-12	Evans Cr.
665	(15*) K-12	Bjorne Cr.
666	(—) J-12	O'Brien Cr.
667	(—) J-12	Anderson Cr.
668	(—) J-12	Ashton Cr.
669	(—) J-12	Larsen Cr.

Continued ...

Appendix II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
670	(—) J-13	Montgomery Cr.
671	(—) K-13	
672	(—) K-12	
673	(—) K-12	Fall Cr.
674	(—) K-12	
675	(—) K-12	Chicken Cr.
676	(—) K-12	Horseshoe Cr.
677	(—) K-12	Hayden Cr.
678	(—) K-12	
679	(15*) K-13	
680	(—) K-12	Thumb Cr.
681	(—) K-12	Hogan Cr.
682	(—) K-12	Snug Harbour Cr.
683	(—) K-12	
684	(—) K-12	South Cr.
685	(15*) K-12	North Cr.
686	(—) K-12	
687	(—) K-12	Sockeye Cr.
687a	(—) K-12	Trail Cr.
688	(—) K-12	
689	(—) K-12	Louis Cr.
690	(15*) K-12	
691	(—) K-12	
692	(—) K-12	Herring Cr.
693	(—) K-12	
694	(—) K-12	
695	(—) K-12	Audrey Cr.
696	(—) K-12	
697	(—) K-12	Barnes Cr.
698	(—) K-12	Mallard Cr.
699	(—) K-12	Cathead Cr.
700	(15*) K-13	
701	(—) K-13	Trap Cr.
702	(—) K-13	Point Cr.
703	(—) K-13	
704	(—) K-13	
705	(15*) K-13	
706	(—) K-13	Logger's Cr.
707	(—) K-13	Macleod Cr.
708	(—) K-13	
709	(—) K-13	
710	(15*) K-13	Hanning Cr.
711	(—) K-13	Quadra Cr.
712	(—) K-13	
713	(—) K-13	
714	(—) K-12-13	
715	(15*) K-12	
716	(—) K-12	
717	(—) K-12	
718	(—) K-12	
719	(—) K-12	
720	(15*) K-12	
721	(—) K-12	
722	(—) K-12	
723	(—) K-12	
724	(—) K-12	
725	(15*) K-12	
726	(—) K-12	Montague Cr.
727	(—) K-12	
728	(—) K-12	
729	(—) K-12	
730	(15*) K-12	
731	(—) K-12	
732	(—) K-12	
733	(—) K-12	
734	(—) K-12	
735	(15*) K-12	
736	(—) K-12	
737	(—) K-12	
738	(—) K-12	Russell Cr.
739	(—) K-12	Swamp Cr.
740	(—) K-12	
741	(15*) K-12	Chalmers Riv.
742	(—) K-12	
743	(—) K-12	
744	(—) K-12	Wilby Cr.
745	(15*) K-12	Wild Cr.
746	(—) K-12	Schuman Cr.
747	(—) K-12	Cabin Cr.
748	(—) K-12	
749	(—) K-12	Shad Cr.
750	(—) K-12	
751	(—) K-12	
752	(—) K-12	Stockdale Cr.
753	(—) K-12	
754	(—) K-12	Dry Cr.
755	(15*) K-12	
756	(—) K-12	Graveyard Cr.
757	(—) K-12	
758	(—) K-12	
759	(—) K-12	Rocky Cr.
760	(15*) K-12	Curran Cr.
761	(—) K-12	
762	(—) K-12	
763	(—) K-12	
764	(—) K-12	
765	(—) K-12	
766	(—) K-12	Carr Cr.
767	(—) K-12	
768	(—) K-12	
769	(—) K-12	Zaikof Cr.
770	(—) K-12	Udall Cr.
771	(—) K-12	McKernan Cr.
772	(—) K-12	
773	(—) K-12	
774	(—) K-12	Rosswog Cr.
775	(15*) K-12	Beach Riv.
775a	(15*) K-12	Pautzke Cr.
776	(—) K-12	
777	(—) K-12	Schooner Cr.
778	(15*) K-12	

Continued …

APPENDIX II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
779	(—)K-13	Nellie Martin Riv.
780	(—)K-13	
781	(—)K-13	
782	(—)K-13	Patton Cr.
783	(—)K-13	
784	(—)K-13	Jeanie Cr.
785	(—)K-13	
786	(—)K-13	
787	(15*)K-13	
788	(15*)K-12	Green Cr.
789	(15*)K-12	Gibbon Cr.
800	(15*)K-12	Lighthouse Cr.
801	(—)K-12	
802	(—)K-12	
803	(—)K-12	English Cr.
804	(—)K-12	
805	(15*)K-12	
806	(—)K-12	Dog Salmon Cr.
807	(—)K-12	Beaver Cr.
808	(—)K-12	
809	(—)K-12	
810	(15*)K-12	Garden Cr.
811	(—)K-12	Etches Cr.
812	(—)K-12	Nuchek Cr.
813	(—)K-12	
814	(—)K-12	
815	(15*)K-12	Constantine Cr.
816	(—)K-12	Bear Cape Cr.
817	(—)K-12	Deer Cr.
818	(—)K-12	Juania Cr.
819	(—)K-12	
820	(15*)K-12	
821	(—)K-12	Brown Bear Cr.
822	(—)K-12	
823	(—)K-12	Johnstone Cr.
824	(—)K-12	
825	(15*)K-12	Eagle Cr.
826	(—)K-12	
827	(—)K-12	Captain Cr.
828	(—)K-12	Cook Cr.
829	(—)K-12	King Cr.
830	(15*)K-12	
831	(—)K-12	Double Cr.
832	(—)K-12	
833	(—)K-12	Bates Cr.
834	(—)K-12	Hardy Cr.
835	(—)K-12	Scott Cr.
836	(—)K-12	Dan's Cr.
837	(—)K-12	
838	(—)K-12	
839	(—)K-12	
840	(15*)K-12	
841	(15*)K-12	Kenny Cr.
842	(15*)K-12	Muddy Cr.
843	(—)K-12	
844	(—)K-12	Makarka Cr.
845	(15*)K-12	
846	(—)K-12	
847	(—)K-12	Hawkins Cr.
848	(—)K-12	
849	(—)K-12	Rollin Cr.
850	(—)K-12	Canoe Cr.
851	(—)K-12	Zillesenoff Cr.
852	(—)K-12	
853	(—)K-12	Whisky Cr.
854	(—)K-12	
855	(15*)K-12	
856	(—)K-12	
857	(—)K-12	
858	(—)K-12	
859	(—)K-12	
860	(—)K-12	
861	(—)K-12	Bernard Cr.
862	(—)K-12	Clamdigger's Cr.
863	(—)K-12	Orca Cr.
864	(—)K-12	
865	(—)K-12	Deep Cr.
866	(—)K-12	Hyde Cr.
867	(—)K-12	
868	(—)K-12	Bluff Cr.
869	(—)K-12	
870	(15*)K-12	FAA Cr.
871	(—)K-12	Derilict Cr.
SOUTHEASTERN ALASKA		
E1	(12)N-14	Limestone Cr.
E1A	(12)N-14	Prospect Cr.
E1B	(12)N-14	
E1C	(12)N-15	Sweetheart Cr.
E1D	(12)N-15	
E1E	(12)N-15	
E1F	(12)N-15	
E2	(10)N-15	Sophia Cr.
E3	(10)N-15	Chuck Riv.
E3A	(10)N-15	Surprise Cr.
E3B	(10)N-15	
E3C	(10)N-15	
E4	(10)N-14	
E4A	(10)N-15	
E4B	(10)N-15	
E5	(10)N-15	
E5A	(10)N-15	
E6	(10)N-15	
E6A	(10)N-15	
E7	(10)N-15	Farragut Riv.
E7A	(10)N-16	Muddy River
E7B	(—)N-16	
E7C	(10)N-15	Cascade Cr.
E7D	(10)N-15	
E8	(10)N-15	Scenery Cr.
E9A	(—)N-14	

Continued ...

APPENDIX II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
E9B	(12) N-14	Hilda Cr.
E9C	(12) N-14	Fish Cr.
E9D	(12) N-14	Sockeye Cr.
E9E	(12) N-14	Yehring Cr.
E9F	(—) N-14	Moose Cr.
E10	(11) N-14	Bear Cr.
E10A	(11) N-14	Admiralty Cr.
E10B	(12) N-14	Peterson Cr.
E10C	(12) N-14	Lake Cr.
E10D	(12) N-14	Salmon Cr.
E10F	(12) N-14	
E10G	(12) N-14	Fish Cr.
E11	(11) N-14	
E12	(11) N-14	King Salmon Cr.
E12A	(—) N-15	
E13	(11) N-14–15	Swan Cove Cr.
E13A	(11) N-15	Pack Cr.
E13B	(11) N-14	
E14	(11) N-15	
E14A	(11) N-15	
E14B	(11) N-15	
E14C	(—) N-15	
E14D	(—) N-15	
E15	(11) N-15	Mole Riv.
E15A	(—) N-15	
E16	(11) N-15	
E17	(11) N-15	
E18	(11) N-15	
E18A	(11) N-15	
E19	(11) N-15	
E20	(11) N-15	
E21	(—) N-15	Old Man's Cr.
E22	(11) N-15	
E22A	(—) N-15	
E23	(11) N-15	
E23A	(—) N-15	
E24	(11) N-15	
E25	(11) N-15	
E25A	(—) N-15	
E26	(11) N-15	
E27	(11) N-15	
E28	(11) N-15	
E28A	(—) N-15	
E28B	(—) N-15	
E28C	(—) N-15	
E28D	(—) N-15	
E29	(11) N-15	
E30	(11) N-15	
E31	(—) N-15	
E31B	(—) N-15	
E31C	(—) N-15	Twelvemile Cr.
E31D	(—) N-15	Fivemile Cr.
E32	(—) N-16	
E32A	(10) N-16	
E33	(10) N-16	Cathedral Falls Cr.
E33A	(10) N-16	Hamilton Cr.
E34	(10) N-16	
E34A	(—) N-16	Big John Cr.
E34C	(10) N-16	Irish Cr.
E35	(9) N-16	Port Camden Cr.
E35A	(—) N-16	
E35B	(9) N-16	
E36	(9) N-16	Kadak Cr.
E37	(9) N-16	
E37B[3]	(9) N-16	
E38	(9) N-16	Straight Cr.
E38A	(—) N-16	
E39	(—) N-16	Saginaw Cr.
E40	(—) N-16	
E40A	(9) N-16	
E41	(9) N-16	
E41A	(—) N-16	
E41B	(—) N-16	
E42	(9) N-16	
E42A	(9) N-16	
E42B	(—) N-16	
E42C	(—) N-16	
E43	(9) N-16	
E43A	(9) N-16	
E43B	(9) N-16	Piledriver Cr.
E43C	(—) N-16	
E43E	(—) N-16	
E43F	(—) N-16	Kwatahein Cr.
E44	(9) N-16	
E44A	(—) N-16	
E44B	(9) N-16	
E44C	(9) N-16	
E44D	(—) N-16	Alecks Cr.
E44E	(—) N-16	
E45	(—) N-16	
E45A	(—) N-16	
E45B	(—) N-16	
E45C	(—) N-16	
E45D	(—) N-16	
E46	(9) N-16	
E46A	(9) N-16	
E46B	(9) N-16	
E46C	(—) N-16	
E47[4]	(9) N-16	Deep Cr.
E47A	(9) N-16	
E47B	(—) N-16	
E48	(9) N-16	
E48A	(9) N-16	
E48B	(9) N-16	
E49	(9) N-16	Sashin Cr.
E49A	(9) N-16	
I1	(13) N-14	
I1A	(13) N-14	

[3] Shown as "E37C" on map.

[4] Shown as "47" on map.

Continued ...

APPENDIX II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
I1B	(13) N-14	
I1C	(13) N-14	
I2	(13) N-14	Neva Cr.
I3	(13) N-14	
I8	(13) M-14	
I9	(11) M-14	
I9A	(—) M-14	
I10	(11) M-14	Humpy Cr.
I11	(—) M-14	
I11A	(11) M-14	
I12	(11) M-14	
I12A	(—) M-14	
I12B	(—) M-14	
I13	(—) M-N-14	
I13A	(—) N-14	
I13B	(11) M-14	
I13C	(—) N-14	
I14	(11) N-14	
I14A	(11) N-14	Chicken Cr.
I14B	(—) N-14	
I15	(11) N-14	Granite Cr.
I16	(11) N-14	Game Cr.
I17	(11) N-14–15	Seagull Cr.
I17A	(—) N-15	Bear Cr.
I17B	(—) N-14	
I18	(—) N-14	
I19	(11) N-14	Humpback Cr.
I20	(11) N-14	Spasski Cr.
I21	(11) N-14	
I22	(—) N-14	
I23	(11) N-14–15	
I24	(11) N-14	
I25	(11) N-14	Hubbard Cr.
I26	(13) N-14	Salmon Riv.
I27	(13) N-14	Bartlett Riv.
I28	(13) N-14	
I28A	(13) N-14	
I29[5]	(13) M-14	
I30	(13) M-14	
I31	(13) M-14	
K1	(7) O-17	Salmon Riv.
K2	(7) O-17	Halleck Riv.
K3	(7) O-17	Tombstone Riv.
K4	(7) O-17	Halibut Cr.
K4A	(—) O-17	
K4B	(—) O-17	
K5	(7) O-17	Sandfly Cr.
K6	(7) O-17	Hidden Cr.
K6A	(—) O-17	
K7	(—) O-18	Cannery Cr.
K8	(7) O-18	Fillmore Riv.
K8A	(—) O-18	
K8B	(—) O-18	
K9	(7) O-18	Canine Cr.
K9A	(—) O-18	
K10	(7) O-18	
K11	(—) O-18	Willard Cr.
K11A	(—) O-18	Flat Cr.
K11B	(—) O-18	
K13	(7) O-18	Nakat Cr.
K13A	(—) O-18	
K13B	(—) O-18	
K14	(—) O-18	Sockeye Cr.
K14A	(—) O-18	
K14B	(—) O-18	
K15	(—) O-18	
K16	(7) O-18	Harry Cr.
K17	(—) O-18	Breakwater Cr.
K18	(7) O-17	Very Cr.
K18A	(—) O-17	
K18B	(—) O-18	
K18C	(—) O-18	
K18D	(—) O-18	
K19	(7) O-17	Kah Shakes Cr.
K19A	(—) O-17	
K20	(7) O-17	Vixen Cr.
K20A	(—) O-17	
K21	(—) O-17	Humpback Cr.
K21A	(—) O-17	Mink Cr.
K22	(—) O-17	Sockeye Cr.
K22–1	(—) O-17	Buschmann Cr.
K22–2	(—) O-17	Cobb Cr.
K23	(7) O-17	Marten Riv.
K23A	(7) O-17	Red Riv.
K24	(7) O-17	Keta Riv.
K25	(—) O-17	Badger Cr.
K26	(—) O-17	
K26A	(—) O-17	
K27	(—) O-17	Black Cr.
K28	(7) O-17	
K28A	(—) O-17	
K29	(—) O-17	
K30	(—) O-17	Carp Cr.
K31	(7) O-17	Skull Cr.
K31A	(—) O-17	
K31B	(7) O-17	Sheridan Cr.
K33	(—) O-17	Bakewell Cr.
K34	(7) O-17	Wilson Riv.
K34–1	(7) O-17	Wilson Riv., East Fork
K34A	(—) O-17	Wolverine Cr.
K35	(7) O-17	Cabin Cr.
K36	(—) O-17	
K36A	(—) O-17	
K37	(7) O-17	Winstanley Cr.
K38	(7) O-18	Checats Cr.
K39	(7) O-17	Big Goat Cr.
K40	(—) O-17	Boulder Cr.
K41	(7) O-17	Rudyerd Riv.
K41A	(—) O-17	

[5] Shown as "29" on map.

Continued ...

APPENDIX II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
K42	(—)O-17	Nooya Cr.
K43	(7)O-17	Walker Cr.
K43A	(—)O-17	
K43B	(—)O-17	
K44	(7)O-17	Chickamin Riv.
K44–	(—)O-17	Basin Cr.
K44–2	(—)O-17	King Salmon Cr.
K44–3	(—)O-17	Humpy Cr.
K44–4	(7)O-17	Barrier Cr.
K44–5	(—)O-17	Clearwater Cr.
K45	(—)O-17	Robinson Cr.
K46	(7)O-17	Saks Cr.
K46A	(—)O-17	Fitzgibbon Cr.
K47	(7)O-16	Klahini Riv.
K48	(7)O-16	Unuk Riv.
K48–	(—)O-17	Clear Cr.
K48–[6]	(7)O-16	Lake Cr.
K48–1	(7)O-16	Eulachon Cr.
K49	(7)O-16	Grant Cr.
K50	(—)O-16–17	Herman Cr.
K51	(—)O-16	Anchor Cr.
K52	(—)O-16	Short Cr.
K53	(—)O-17	Shelokum Cr.
K54	(7)O-17	Yes Riv.
K54A	(—)O-17	
K54B	(—)O-17	
K54–1	(7)O-16–17	Hatchery Cr.
K55	(—)O-17	Spacious Cr. (Wasta Cr.)
K55A	(—)O-17	
K55B	(—)O-17	
K55C	(—)O-17	
K55D	(—)O-17	Heckman Cr.
K56	(—)O-17	Stewart Cr.
K56A	(—)O-17	
K57	(7)O-17	Raymond Cr.
K58	(—)O-17	Helm Cr.
K59	(—)N-17	
K60	(7)O-N-17	Smugglers Cr.
K61	(—)O-17	
K62	(7)N-17	Niblack Cr.
K63	(7)N-17	Jim Cr.
K64	(7)N-17	Wolf Cr.
K65	(—)N-17	Meyers Cr.
K66	(7)N-17	Black Bear Cr.
K66A	(—)N-17	
K67	(7)N-17	Alava Cr.
K68	(7)O-18	Narrow Pass Cr.
K69	(7)O-17	
K70	(—)O-17	Swansons Cr.
K71	(—)O-17	
K72	(7)O-18	Ella Cr.
K73	(—)O-17	
K74	(—)O-17	Manzanita Cr.
K75	(—)O-17	Grace Cr.
K76	(—)O-17	Snip Cr.
K77	(7)O-17	Portage Cr.
K78	(—)O-17	Indian Cr.
K79	(7)O-17	Cow Cr.
K80	(7)O-17	Beaver Cr.
K81	(7)O-17	Bell Cr.
K82	(7)O-17	Klu Cr.
K82A	(—)O-17	Klam Cr.
K83[7]	(7)O-17	Neets Cr.
K84	(7)O-17	Traitors Cr.
K85	(7)O-17	Margaret Cr.
K86	(—)O-17	Loring Cr.
K87	(7)O-17	Naha Riv.
K87A	(—)O-17	Steelhead Cr.
K88	(—)O-17	Wolf Cr.
K89	(—)O-17	Moser Cr.
K89A	(—)O-17	
K90	(—)O-17	Ward Cr.
K90A	(—)O-17	Carlana Cr.
K91	(—)O-17	Ketchikan Cr.
K92	(—)O-17	Herring Cr.
K93	(—)O-17	Mahoney Cr.
K94	(7)O-17	White Riv.
K95	(—)O-17	Leask Cr.
K96	(—)O-17	Salt Cr.
K96A	(—)O-17	
K97	(—)O-17	
K98	(—)O-17	Nigelius Cr.
K99	(7)O-17	Carroll Riv.
K99A	(—)O-17	Swan Cr.
K99B	(—)O-17	
K99C	(—)O-17	
K100	(7)O-17	Spit Point Cr.
K101	(7)O-17	
K101A	(—)O-17	
K102	(—)O-17	
K103	(—)O-17	Fish Cr.
K104	(7)O-17	Sea Level Cr.
K105	(7)O-17	Lucky Cr.
K106	(7)O-18	Pond Cr.
K107	(—)O-18	
K107A	(—)O-18	
K108	(7)O-17	Tamgas Cr.
K108A	(—)O-17	
K109	(7)O-17	
K110	(—)O-17	Kwain Cr.
K111	(7)O-17	Crab Cr.
K111A	(—)O-17	
K112	(—)O-17	Bush Cr.
K113	(—)O-17	Trout Cr.
K114	(7)O-17	Bostwick Cr.
K114A	(—)O-17	
K115	(—)O-17	
K116	(—)O-17	Vallenar Cr.

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[6] Shown as "K48" on map.

[7] Shown as "K13" on map.

Continued ...

APPENDIX II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
K116A	(—)O-17	
K117	(7)O-17	
K117A	(—)O-17	
K117B	(7)O-17	Dall Cr.
K119	(8)N-18	
K120	(8)N-18	
K121	(—)N-18	
K121A	(—)N-18	
K122A	(—)N-18	
K123	(—)N-18	
K123A	(—)N-18	
K124	(8)N-18	
K125	(8)N-18	
K126	(—)N-18	
K127	(8)N-18	Johnson Cr.
K128	(—)N-18	Perkins Cr.
K129	(—)N-18	
K130	(8)N-18	
K131	(—)N-18	
K132	(8)N-18	
K133	(—)N-17	Frederick Cr.
K133A	(8)N-18	
K134	(—)N-17–18	
K134A	(—)N-17	
K134B	(—)N-17	
K135	(8)N-17	
K135A	(—)N-17	
K135B	(—)N-17	
K136	(—)N-17	Kegan Cr.
K137	(—)N-17	Aiken Cr.
K138	(—)N-17	Miller Cr.
K138A	(—)N-17	
K139	(8)N-17	Dolomi Cr.
K140	(—)N-17	
K141	(—)N-17	
K142	(—)N-17	
K143	(—)N-17	
K144	(—)N-17	
K145	(—)N-17	
K146	(—)N-17	
K147	(—)N-17	
K148	(—)N-17	Dora Cr.
K149	(—)N-17	
K150	(8)N-17	Disappearance Cr.
K151	(—)N-17	
K152	(—)N-17	Cannery Cr.
K153	(—)N-17	Tom Cr.
K154	(—)N-17	Lagoon Cr.
K155	(8)N-17	
K155A	(—)N-17	
K156	(8)N-17	Sunny Cr.
K156A	(—)N-17	
K157	(—)N-17	Clover Cr.
K158	(—)N-17	
K159	(—)N-17	
K160	(8)N-17	Saltery Cr.
K160A	(—)N-17	
K161	(—)N-17	
K162	(8)N-17	Omar Cr.
K162A	(—)N-17	
K163	(—)N-17	Old Toms Cr.
K164	(—)N-17	
K165	(8)N-17	Polk Cr.
K165A	(—)N-17	
K166	(—)N-17	Rock Cr.
K167	(—)N-17	Dog Salmon Cr.
K168	(—)N-17	
K169	(8)N-17	Cabin Cr.
K170	(—)N-17	Old Franks Cr.
K171	(—)N-17	
K171A	(—)N-17	
K172	(—)N-17	Ives Cr.
K173	(—)N-17	
K174	(—)N-17	Kina Cr.
K175	(8)N-17	Twelvemile Cr.
K175A	(—)N-17	
K175B	(—)N-17	
K176	(8)N-17	Harris Riv.
K176-1	(—)N-17	Indian Cr.
K177	(8)N-17	Maybeso Cr.
K177A	(—)N-17	
K178	(8)N-17	Karta Riv.
K179	(—)N-17	Young Cr.
K180	(—)N-17	
K180A	(—)N-17	
K181	(—)N-17	
K182	(—)N-17	
K183	(8)N-17	
K183A	(—)N-17	
K184	(8)N-17	Thorne Riv.
K184-1	(—)N-17	Gravelly Cr.
K185	(—)N-17	
W1	(13)N-13	Chilkat Riv.
W2	(13)N-13	Chilkoot Riv.
W3	(13)N-13	
W3A	(13)N-13	
W2B	(13)N-13	
W4	(11)N-15	Three Peak Riv.
W4A	(11)N-15	
W5	(11)N-15	
W6	(11)N-15	
W6A	(—)N-15	Harley Cr.
W7	(11)N-15	
W8	(11)N-14–15	
W9	(11)N-15	
W9A	(11)N-15	
W10	(11)N-15	
W11	(11)N-15	
W11A	(—)N-15	
W12	(11)N-15	Indian Cr.

Continued ...

APPENDIX II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
W12A	(—)N-15	Eaton Cr.
W13	(11)N-15	
W14	(11)N-15	
W14A	(11)N-15	
W14B	(11)N-15	
W14C	(11)N-15	
W16	(11)N-15	Kook Cr.
W17	(11)N-15	
W17A	(11)N-15	
W18	(11)N-15	
W19	(11)N-15	
W20	(11)N-15	
W21	(11)N-15	
W22	(11)N-15	
W23	(11)N-15	
W24	(—)N-15	
W25	(—)N-15	Granite Cr.
W25A	(—)N-15	
W26	(11)N-15	
W26A	(—)N-15	
W27	(11)N-15	
W27A	(11)N-15	
W28	(—)N-15	
W28A	(11)N-15	
W29	(11)N-15	
W30	(11)N-15	
W31	(9)N-15	
W32	(9)N-15	
W33	(9)N-15	Rodman Cr.
W34	(9)N-15	
W34A	(9)N-15	
W35	(9)N-15	Peschan Riv.
W36	(—)N-15	Lake Eva Cr.
W37	(—)N-15	
W38	(9)N-15	
W39	(9)N-15	
W40	(9)N-15	
W41	(9)N-15	Clear Riv.
W41A	(9)N-15	Glacial Riv.
W42	(—)N-14	
W42A	(11)N-14	
W43	(—)N-14	
W44	(11)N-14	Greens Cr.
W44A	(—)N-14	Two Island Cove Cr.
W45	(11)N-14	Wheeler Cr.
W45A	(11)N-15	Lake Kathleen Cr.
W46	(11)N-15	Ward Cr.
W47	(11)N-15	Lake Florence Cr.
W48	(11)N-15	Fishery Cr.
W49	(11)N-15	Thayer Cr.
W50	(11)N-15	
W51	(11)N-15	
W52	(11)N-15	Hasselborg Cr.
W53	(11)N-15	
W54	(11)N-15	
W55	(11)N-15	
W56	(11)N-15	
W57	(11)N-15	
W58	(11)N-15	
W59	(11)N-15	
W60	(11)N-15	
W61	(9)N-16	
W62	(9)N-16	
W62A	(9)N-16	
W63	(9)N-16	
W64	(9)N-16	
W65	(9)N-15	
W65A	(9)N-15	Katlian Riv.
W65B	(9)N-15	
W65C	(9)N-15	
W66	(9)N-15	
W67	(9)N-15	Indian Riv.
W67B	(11)N-15	
W68	(11)N-15	
W68A	(—)N-15	
W69[8]	(11)M-15	
W69A	(—)M-15	
W70	(11)M-15	
W71	(11)M-15	
W72	(—)M-15	
W72A	(11)M-N-15	
W73	(11)M-15	
W74	(11)M-14	
W75	(11)M-14	
W76	(11)M-N-15	Phonograph Cr.
W77	(11)N-15	
WC1	(—)N-18	Hessa Cr.
WC2	(—)N-18	Hunter Cr.
WC3	(—)N-18	
WC4	(—)N-18	Max Cr.
WC5[9]	(8)N-17	Klakas Lake Cr.
WC6	(—)N-17	
WC6A	(—)N-17	
WC6B	(—)N-17	
WC6C	(—)N-18	
WC7	(—)N-17	Clam Cr.
WC8[9]	(8)N-17	
WC9	(8)N-18	Mabel Cr.
WC9A	(—)N-17	
WC9B	(—)N-17	
WC10[9]	(8)N-17	
WC10A	(—)N-17	
WC10B	(—)N-17	
WC10C	(8)N-17	
WC11	(8)N-17	Nutkwa Cr.
WC12	(—)N-17	Hetta Lake Cr.
WC13	(—)N-17	Copper Cr.
WC14	(8)N-17	Portage Cr.

[8] Shown as "W64" on map.

[9] Shown as "5", "8", "10", "20", on map.

Continued ...

APPENDIX II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
WC15	(8) N-17	Beaver Cr.
WC16	(—) N-17	Deer Cr.
WC17	(8) N-17	Eek Lake Cr.
WC18	(8) N-17	Hydaburg Cr.
WC18A	(—) N-17	
WC19	(8) N-17	Waterfall Cr.
WC20[9]	(8) N-18	
WC21	(8) N-18	Grace Cr.
WC22	(—) N-18	Vesta Cr.
WC23	(8) N-18	Rose Cr.
WC24	(8) N-17	Coco Cr.
WC25	(8) N-17	Kasook Lake Cr.
WC26	(8) N-17	
WC27	(8) N-17	
WC28	(—) N-17	Estrella Cr.
WC29	(—) N-17	Caldera Cr.
WC30	(8) N-17	
WC31	(8) N-17	
WC32	(8) N-17	Soda Cr.
WC35	(8) N-17	Trocadero Cr.
WC36	(—) N-17	
WC37	(—) N-17	
WC38	(—) N-17	
WC39	(8) N-17	Klawak Cr.
WC40	(8) N-17	Dog Salmon Cr.
WC41	(8) N-17	
WC42	(—) N-17	
WC43	(—) N-17	Steelhead Cr.
WC44	(—) N-17	
WC45	(8) N-17	
WC46	(8) N-17	
WC47	(8) N-17	
WC48	(8) N-17	
WC49	(—) N-17	
WC50	(8) N-17	
WC51	(8) N-17	Shaheen Cr.
WC52	(8) N-17	Staney Cr.
WC53	(8) N-17	
WC54	(—) N-17	Naukati Cr.
WC55	(8) N-17	
WC56	(8) N-17	Sarkar Cr.
WC57[10]	(8) N-16	Camp Taylor Cr.
WC58	(—) N-16	
WC59	(—) N-16	Wolf Cr.
WC60	(—) N-16	El Capitan Cr.
WC61	(—) N-16	Bear Cr.
WC62	(—) N-16	Sutter Cr.
WC63	(—) N-16	Smith Cr.
WC65	(8) N-16	
WC66	(8) N-16	Devilfish Cr.
WC67	(—) N-16	Tokeen Cr.
WC68	(—) N-16	
WC69	(—) N-16	
WC70	(8) N-16	Holbrook Cr.

[10] Shown as "WR57" on map.

No.	Subarea (Fig. 2) and coordinate (Fig. 2)	Name, if any
WC71	(—) N-16	
WC72	(—) N-16	Van Sant Cr.
WC73	(8) N-17	
WC74	(—) N-17	Edna Cr.
WC75	(8) N-17	
WC76	(—) N-17	
WC77	(8) N-17	
WC78	(8) N-17	
WC79	(—) N-17	
WC80	(8) N-17	
WR1	(10) N-16	Jap Cr.
WR2	(10) N-16	
WR3-1	(7) N-16	Andrew Cr.
WR3-2	(—) N-16	North Arm Cr.
WR4	(7) N-16	Crittenden Cr.
WR5	(—) N-16	Mill Cr.
WR6	(7) O-16	Aaron Cr.
WR7	(7) O-16	Marten Cr.
WR8	(7) O-16	Frank's Cr.
WR9	(—) N-16	Tom Cr.
WR10	(7) O-16	Harding Riv.
WR11	(7) N-16	Bradfield Riv. N.
WR12	(7) N-16	Bradfield Riv. E.
WR13	(7) O-16	Eagle Riv.
WR13-1	(7) O-16	
WR14	(—) O-16	Anan Bay Cr.
WR15	(7) O-16	Anan Cr.
WR16	(—) N-16	Frosty Cr.
WR17	(—) O-17	Santa Anna Cr.
WR18	(—) O-17	Sunny Cr.
WR19	(7) O-17	
WR20	(7) N-17	Emerald Cr.
WR22	(7) N-17	Vixen Cr.
WR23	(—) N-16	
WR24	(7) N-16	
WR25	(7) N-16	Fools Cr.
WR26	(—) N-16	Southeast Cr.
WR27	(—) N-16	Thoms Cr.
WR28[11]	(8) N-16	Kunk Cr.
WR29	(8) N-16	
WR30	(—) N-16	
WR31	(8) N-16	Snake Cr.
WR32	(8) N-16	Menefee Cr.
WR33	(8) N-16	
WR34	(—) N-17	
WR35	(8) N-17	Kuday's Cr.
WR36	(8) N-16	
WR37	(—) N-16	McHenry Lake Cr.
WR38	(—) N-16	Navy Cr.
WR39	(8) N-16	
WR40	(8) N-16	
WR41	(—) N-16	Streets Lake Cr.
WR42	(8) N-16	Porcupine Cr.
WR43	(8) N-16	

[11] Shown as "28" on map.

Continued ...

APPENDIX II. Continued.

No.	Subarea (Fig. 2) and coordinate (Fig. 3)	Name, if any
WR44	(8) N-16	
WR45	(—) N-16	
WR46	(8) N-16	
WR47	(8) N-16	
WR48	(—) N-16	
WR49	(8) N-16	St. John Cr.
WR50	(10) N-16	
WR51	(—) N-16	
WR52	(10) N-16	Big Cr.
WR53	(10) N-16	
WR54	(10) N-16	
WR55	(10) N-16	Fall Cr.
WR56	(10) N-16	Petersburg Cr.
WR57	(10) N-16	Ohmer Cr.
WR58	(10) N-16	Duncan Cr.
WR59	(10) N-16	
WR60	(10) N-16	
WR61	(10) N-16	Castle Riv.
WR62	(10) N-16	Kah Sheets Cr.
WR63	(10) N-16	Totem Cr.
WR64	(10) N-16	
WR65	(10) N-16	Barrie Cr.
WR66	(—) N-16	Loveless Cr.
WR67	(10) N-16	Tunehean Cr.
WR68	(9) N-16	
WR69	(—) N-16	
WR70	(9) N-16	
WR71	(9) N-16	
WR72	(9) N-16	
WR73	(—) N-16	
WR73A	(—) N-16	
WR74	(—) N-16	
WR74A	(—) N-16	
WR75	(—) N-16	
WR75A	(—) N-16	
WR76	(9) N-16	
WR76A	(—) N-16	
WR77[12]	(9) N-16	
WR78	(—) N-16	
WR79	(—) N-16	
WR79A	(—) N-16	
WR80	(—) N-16	
WR81	(9) N-16	
WR82	(—) N-16	
WR83	(—) N-16	
WR84	(9) N-16	
WR85	(9) N-16	
WR86	(9) N-16	
WR87	(9) N-16	
WR88	(—) N-16	
WR89	(8) N-16	Trout Cr.
WR90	(—) N-16	
WR91	(8) N-16	Shipley Cr.
WR92	(8) N-16	Marble Cr.
WR93	(8) N-16	Calder Cr.
WR94	(8) N-16	
WR95	(—) N-16	
WR96	(—) N-16	Flicker Cr.
WR97	(8) N-16	Alder Cr.
WR98	(8) N-16	Buster Cr.
WR99	(8) N-16	
WR100	(—) N-16	
WR101	(—) N-16	Big Cr.
WR102	(8) N-16	Pine Cr.
WR103	(—) N-16	
WR104	(8) N-16	Squaw Cr.
WR105	(8) N-16	Whale Pass
WR106	(8) N-16	
WR107	(8) N-17	
WR108	(8) N-17	Coffman Cr.
WR109	(8) N-17	Eagle Cr.
WR110	(8) N-17	

[12] Shown as "77" on map.

3. Neutron Activation Analysis of Stable Dysprosium Biologically Deposited in the Bone of Chinook Salmon Fingerlings, *Albert L. Babb, William P. Miller, William E. Wilson, Jr., Gene L. Woodruff (U of Wash), Anthony J. Novotny (US Bur Comm Fisheries)*

The tagging of fish is an essential step in studies of their migration, population patterns, and mortality rates. The introduction of an element such as dysprosium not normally present in fish, and the subsequent detection of the element using neutron activation analysis, has some potentially significant advantages over conventional tagging techniques. These advantages include improved discrimination from controls, greater effeciency and economy in the tagging of large numbers, and the possibility of obtaining longer-lasting identification (provided the element used has a sufficiently long biological half-life). Although the use of radioactive tracers is attractive, for the same reasons their use is not permitted in the natural environment by current AEC regulations.

A study has been made of the feasibility of tagging fish by introducing stable dysprosium into Chinook salmon fingerlings. Five hundred fish having fork lengths of 83 to 91 mm were divided into 10 groups of 50 each with 3 of the groups maintained as controls. The remaining groups were used to test various methods of administering dysprosium (in the form of the soluble chloride) to the salmon. One group was used for weekly intramuscular injections of 163 μg of dysprosium. One group was placed into a solution containing 0.1-ppm dysprosium for 24 h once a week for five weeks. Two groups were placed on forced feeding plans of 354 and 605 μg of dysprosium per pellet twice weekly. The remaining groups were placed on voluntary feeding programs in which the fish in the three groups could be normally expected to ingest 200, 300, and 500 μg of dysprosium daily.

Samples were prepared for irradiation in a similar manner in all cases. After steaming for five minutes, the vertebral column and the chondral bones of the head were removed and then dry ashed for 24 h at 650°C. Samples were then ground into a fine powder and 25 mg removed and irradiated for one minute in a thermal-neutron flux of 8×10^{10} n/(cm^2 sec). A few analyses were also performed of whole, wet spleens weighing a few mg each.

The activity of 75-sec ^{165m}Dy was measured after a decay time of 15 sec by counting the 108-keV photopeak for one minute with a $1\frac{3}{4}$- × 2-in. NaI well-crystal connected with a 512-channel analyzer. A purely instrumental method of analysis was used in which spectrum stripping was accomplished with the use of control samples.

The results showed that the amount of dysprosium in the 25-mg samples was less than 2×10^{-8} g ($\lesssim$ 1 ppm) for every method used for dysprosium spiking with the exception of intramuscular injections. In the latter case, dysprosium concentrations were approximately 70 ppm following one injection and approximately 200 ppm after two or more injections. These results are not consistent with previously reported results involving yttrium in fish[1] or lanthanum in rats[2] both of which showed significantly greater retention of the administered elements.

Although the only successful method of Dy spiking employed in the present work, intramuscular injection, is not an acceptable method due to increased mortality and the complicated handling required, the general approach has not been shown to be impractical. The use of larger samples and/or higher neutron fluxes might produce adequate sensitivity for successful tagging.

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1. H. BOROUGHS, J. TOWNSLEY, and R. W. HIATT, "The Metabolism of Radio Nuclides by Marine Organisms. II. The Uptake Accumulation and Loss of Yttrium-91 by Marine Fish and the Importance of Short-lived Radio Nuclides in the Sea," *Biol. Bull.*, **3**, 352 (1950).
2. J. JOWSEY, R. E. ROLAND, and J. H. MARSHALL, "The Deposition of the Rare Earths in Bone," *Radiation Res.*, **8**, 490 (1958).

Reprinted from Transactions of
the American Nuclear Society,
vol. 10, no. 2, 1967

Proceedings of the National Shellfisheries Association
Volume 57 — June 1967

STATISTICS OF THE NEW JERSEY SURF CLAM FISHERY — 1965

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ABSTRACT

New Jersey landings of surf clams (*Spisula solidissima*) have increased greatly since 1943, while the contributions of other middle Atlantic states have declined and are now of minor significance. The marked increase in landings from 1957 (15 million pounds of meat) to 1965 (43.7 million pounds) can be attributed to the New Jersey fishery. Greater demand for the product and increased gear efficiency have both played their part in this rise.

Since 1959, surf clam fishing effort has stabilized and is concentrated in the area between Point Pleasant and Barnegat Lightship. A fleet of about 50 boats is based at Point Pleasant, with a few (7-9) boats at Cape May-Wildwood and Barnegat Inlet. In 1965 considerable effort was expended near Barnegat Lightship. In the spring a dense bed of small clams inshore at Cape May was heavily exploited. Record landings in 1965 were due in part to large catches of these small clams. Landings at Cape May exceeded those at Point Pleasant in March. Mean lengths of total samples by month at Point Pleasant were consistent at 6 inches throughout 1965. Mean lengths of Cape May samples were 5 to 6 inches.

Average catch and effort at Point Pleasant in 1965 reached a low of 607 pounds per hour in February and a high of 744 pounds per hour in September. Observations on commercial vessels at sea revealed that the amount of clams discarded is usually insignificant and rarely exceeds one bushel per trip.

Length-meat weight ratios indicated that meats from inshore Cape May clams were similar in weight to meats from offshore Point Pleasant clams of the same shell length. Monthly per cent solids of clams from Point Pleasant and Cape May were determined in 1965 and values were not significantly different between the two locations.

Proceedings of the National Shellfisheries Association
Volume 57 — June 1967

TOTAL SOLIDS AND LENGTH-WEIGHT RELATION OF THE SURF CLAM, *SPISULA SOLIDISSIMA*

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ABSTRACT

Commercial-size surf clams from New Jersey were sampled monthly to determine seasonal variation in percentage of total solids. Surf clams had a higher percentage of total solids than soft-shell clams, Mya arenaria, *and oysters,* Crassostrea virginica, *but the annual range of values was less.*

Ratios of shell measurements (height/length, width/length, width/height) for clams from Point Pleasant and Cape May were similar.

The relation of shell length to wet weight of meat for clams from Point Pleasant and Cape May was similar to that for clams from Long Island, New York.

Losses in meat weight from the industry's practice of removing stomach and gonad tissue varied from 11 to 20 per cent, depending on shell length and month of collection.

INTRODUCTION

The surf clam (*Spisula solidissima)* is the most valuable species in the commercial fishery of New Jersey; record landings of 42.3 million pounds of meats, worth 3.0 million dollars, were made in 1965 (LoVerde, 1966). This species attains a length of 8 inches and the meat may weigh 1 pound. Surf clams occur off the New Jersey coast from the intertidal zone to depths over 200 feet. They are taken commercially in depths of 20 to 110 feet by vessels using hydraulic dredges (Groutage and Barker, 1967). Clams are landed unshucked, and the entire body, except for the stomach and gonads, is utilized. Cleaned meats are minced for chowder and dips, or cut into strips for frying.

Purposes of this study were to: determine seasonal variation in percentage of total dry solids; establish the length-weight relation (total length of shell and wet weight of meat) for clams from Point Pleasant and Cape May; compare shell dimensions of clams from two areas of the fishery; and determine loss in meat weight during processing by the industry.

MATERIALS AND METHODS

Samples of surf clams were collected monthly in 1965, and less frequently in 1966, from a location off Point Pleasant, New Jersey; other collections were made in May 1965 and November 1966 off Cape May, New Jersey (Fig. 1). The live clams were brought to the laboratory and shucked. The entire meats were then washed, drained for 10 minutes, and placed on paper towels to remove surface water. Meat weight was recorded to the nearest gram, and shell measurements to the nearest millimeter. Shell measurements are defined as: length (L) — greatest dimension; height (H) — greatest dorsoventral distance; and width (W) — thickness of the clam with both valves in place.

To determine total dry solids, one clam was selected from each 10-mm group (120-160 mm). Meats from these five clams were homogenized in a high-speed blender and 20-gram portions were dried. Drying procedures followed the oven-dry method used by Engle (1958) and the freeze-dry method used by Shaw, Tubiash, and Barker

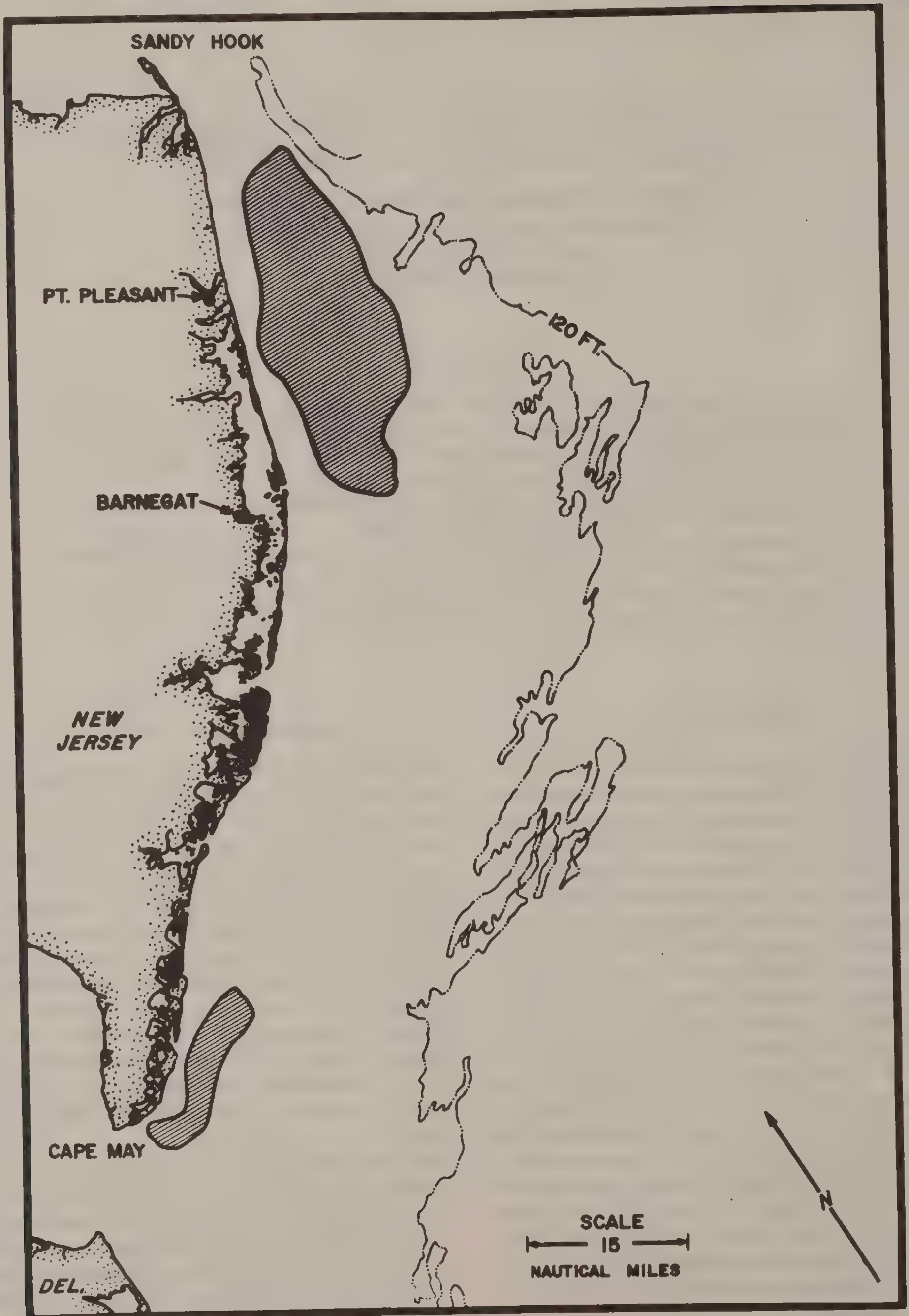
SANDY HOOK
PT. PLEASANT
BARNEGAT
NEW JERSEY
CAPE MAY
DEL.
120 FT.
SCALE
15
NAUTICAL MILES
N

FIG. 1. *Areas of major surf clamming effort off New Jersey showing sampling locations in 1965 and 1966.*

(1966). Both methods gave essentially the same results. Percentage of total dry solids was obtained by dividing the dry weight of the meat by the wet weight, and multiplying by 100 (Engle, 1958).

Length-weight relationships were derived by measuring shell lengths and weighing the entire meats. Mean weights for length-groups were calculated by combining all samples from the same area.

Percentage loss in meat weight from processing was derived by weighing individual meats before and after removal of stomach and gonads.

TOTAL SOLIDS

Percentages of total dry solids derived by oven-drying Point Pleasant clams, collected in 1965, are presented in Figure 2. For 1965 the mean was 21.4 per cent and the range 18.1 per cent (in January) to 23.5 per cent (in April). A major fluctuation occurred during winter, when low water temperatures may reduce feeding and gonad development. Minor decreases in June and October coincide with the spawning periods. The large, muscular foot represents a high percentage of the total meat weight; here probably is the primary reason for the small seasonal variation in total solids.

The oven-dry method permitted comparison of percentage of total solids of surf clams with values found by other investigators for oysters, *Crassostrea virginica,* and soft-shell clams, *Mya arenaria.* The annual mean (and range) in percentages of total solids from selected areas were: surf clam, New Jersey — 21.4 (18.1-23.5); oyster, Chesapeake Bay (Engle, 1958) — 17.0 (14.0-20.0); soft-shell clam, Maine (Harriman, 1954) — 18.4 (15.2-21.5).

SHELL MEASUREMENTS

Shell shape may influence the volume of the shell cavity and, consequently, the amount of clam meat. The extent of shell variation must be known to allow valid comparisons of shell length-meat weight relationships of clams from different areas and of different lengths.

Shells of clams from inshore populations appeared to be more globose and less pointed than shells of clams from offshore areas. To determine if this was true, 2-bushel samples taken from deep (80 feet) water off Point Pleasant and shallow (22 feet) water off Cape May were compared.

Cape May clams were smaller than Point Pleasant clams. Lengths ranged from 102 to 133 mm (mean 119 mm) at Cape May and from 127 to 168 mm (mean 151 mm) at Point Pleasant. In Table 1, the data are arranged in centimeter length-groups, and ratios of the measurements (H/L, W/L, and W/H) are shown for these groups within each sample and between areas.

All three ratios were higher for Cape May clams. These ratios decreased gradually, however, as length increased. The larger Point Pleasant clams showed the same tendency — the longest length-groups had the lowest ratios. The greatest difference between two individuals in these samples was 0.12. Variation was much less, however,

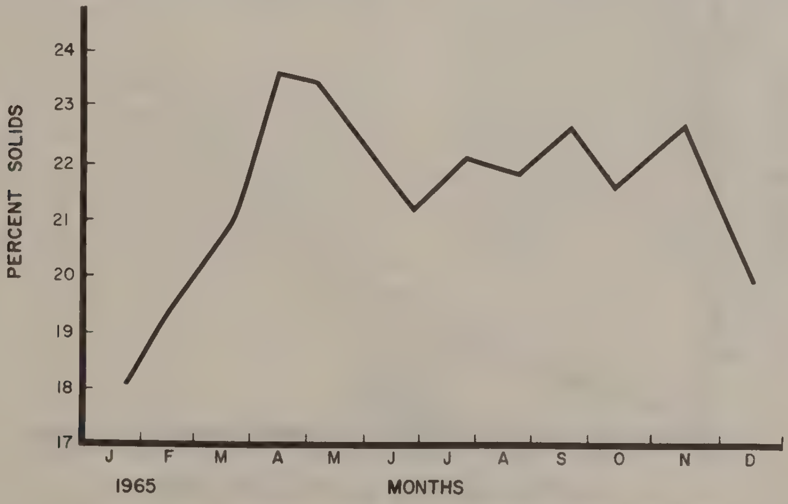

FIG. 2. *Percentage of total dry solids of surf clams from Point Pleasant, N. J., in 1965.*

TABLE 1. *Ratios of shell measurements, height/length (H/L), width/length (W/L), width/height (W/H) of surf clams taken off Cape May and Point Pleasant, New Jersey, in 1966.*

Length-Groups (mm)	Ratios		
	H/L	W/H	W/L
Cape May			
100-109	0.71	0.61	0.43
110-119	0.71	0.61	0.43
120-129	0.70	0.59	0.41
130-139	0.69	0.59	0.41
Point Pleasant			
130-139	0.70	0.60	0.41
140-149	0.69	0.59	0.41
150-159	0.68	0.58	0.40
160-169	0.68	0.58	0.40

when data from all clams of the same length were combined. The ratio decrease for each length-group for Point Pleasant and Cape May samples did not exceed 0.02 and for the combined samples 0.03.

The ratio variation between length-groups indicates that smaller clams are slightly more globose and less pointed than larger ones. The shapes of clams in these samples are a function of shell length; area of capture or water depth apparently had no influence on shape.

LENGTH-WEIGHT RELATIONSHIP

The shell length-meat weight relationship for 2,230 Point Pleasant clams is presented in Figure 3. Meat weights were generally constant throughout the year, although a slight decrease was evident during the spawning period. Weight increased rapidly in clams longer than 150 mm, which is the average length landed at Point Pleasant.

Meat weights of Point Pleasant and Cape May clams of corresponding lengths were similar. Shell length-meat weight relations for Point Pleasant and Cape May clams are also similar to the meat weight for surf clams from Long Island, New York (Westman and Bidwell, 1946).[1]

WEIGHT LOSS DUE TO CLEANING

Surf clams are shucked by hand in the plants, and stomach and gonad tissue is removed during cleaning. In this study, clams of all lengths from Point Pleasant and Cape May were cleaned to determine the relationship between shell length and percentage loss of meat weight. Two-bushel samples were obtained before and after the spawning period to evaluate the effects of gonad development on meat weight. About 150 clams from Point

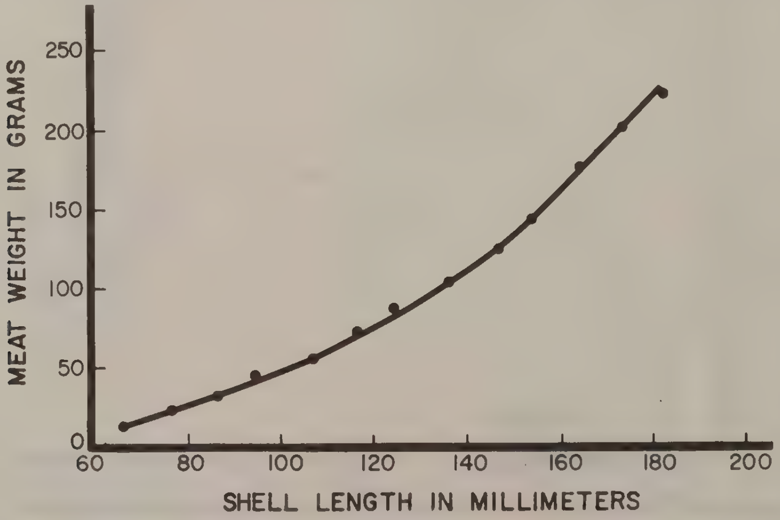

FIG. 3. *Shell length-meat weight relationship of surf clams from Point Pleasant, N. J., in 1965.*

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[1] Westman, James R. and Milton H. Bidwell. The surf clam. Economics and biology of a New York marine resource. Mimeographed. Copy on file at Bureau of Commercial Fisheries, Oxford, Md.

TABLE 2. *Percentage weight loss due to removal of stomach and gonad tissue from meats of surf clams taken off Cape May and Point Pleasant, N. J., in 1965 and 1966.*

Length-groups (mm)	May 1965		November 1966	
	Point Pleasant %	Cape May %	Point Pleasant %	Cape May %
100-109	—	—	—	12
110-119	16	19	—	12
120-129	16	20	—	12
130-139	16	20	13	13
140-149	15	18	12	12
150-159	15	—	11	—
160-169	13	—	11	—

Pleasant and from Cape May were examined in May 1965, before spawning had started, and in November 1966, after spawning had ended. The May 1965 sample from Point Pleasant was collected at sea, aboard a commercial vessel, to obtain smaller clams for comparison with Cape May clams of identical lengths. Most samples were obtained directly from the boats when they returned to port with the day's catch.

Comparison of meat weights before and after cleaning revealed losses of 11 to 20 per cent; losses varied with shell length and month (Table 2). The weight loss was less for the largest clams from both areas in May, but decreases for all clams were similar in November. Point Pleasant clams had losses of 13 to 16 per cent in May and 11 to 13 per cent in November. Cape May clams had losses of 18 to 20 per cent in May and 12 to 13 per cent in November.

Since the annual mean weights of wet meats from clams of corresponding lengths at Point Pleasant and Cape May were similar, the greater loss from cleaning Cape May clams in May 1965 may be related to an earlier seasonal increase in gonad weight. In May 1965 bottom water temperatures were significantly higher in shallow water close to Cape May than in deep water off Point Pleasant. The mean temperature at five stations within the area of greatest clamming effort off Cape May was 10.0°C (range, 7.5 to 12.3°C) whereas the mean for five stations in the Point Pleasant area was 5.4°C (range, 5.1 to 5.7°C). In November 1966, bottom water temperatures were similar in both areas and all clams had recently spawned; thus, weight loss from cleaning was minimal.

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THE IMPACT OF COMPUTERS ON SCIENCE

Richard A. Barkley*

By way of introduction, let me tell you a story which is probably too good to be true. The Prussian Army is said to have classified its officers into four categories: brilliant and lazy, brilliant and energetic, stupid and lazy, and stupid and energetic. The brilliant and lazy were the most valuable, because they knew what should be done and got others to do it; they made the best generals. The brilliant and energetic knew what should be done and did it; they made good staff officers. The stupid and lazy were of no particular value, but they could be put to work fairly safely. Finally, the stupid and energetic, who applied their energy to making mistakes, were considered dangerous and had to be weeded out.

Let's see what counterparts to the four categories of Prussian officers we can find in today's world of science. Let me be a bit generous and say that my scientific colleagues are all brilliant and lazy, although actually quite a few of them are very energetic. At the other extreme, the computer is the epitome of stupidity and energy, as you may already know if you have done any computer programming, or have tried to straighten out an account which a badly programmed computer has tied into knots. This brings us to the brilliant and energetic category, where I will place computer programmers. Their job is to teach computers to behave as if they were brilliant, without sacrificing too much of the computer's energy. As to the stupid and lazy, there is some evidence that they may have helped design certain computers, which are no longer on the market.

Scientists have been around quite a bit longer than computers, and I suspect they have not changed very much since the first computers came on the market in 1950.[1] Science at its best is a highly personal and individual activity which makes use of intuition as well as logic to arrive at new concepts based upon insufficient and conflicting data. This process is very poorly understood, but it does seem to demand creativity of an order well beyond that of which present computers are capable. But science is more than new concepts. New concepts must be tested by formulating hypotheses which are capable of being supported or disproven through experiment. Experiments must then be designed and carried out to test these hypotheses. And data must be collected, reduced, analyzed, and applied to the problem. Finally, if the results are adequate, the entire sequence must be written up for publication. Once this is done, the research scientist turns back to the first step and repeats the cycle, while the applied scientist and then the engineer pick up the thread which was spun by the research scientist and weave it into the fabric of technology.

How much direct influence has the computer had on all of these procedures? At the highest creative level, none at all. Formulating hypotheses, the next step, could probably be done today in fields like organic chemistry—which are well-structured—by a properly programmed computer, using the tools of symbolic logic. Design of experiments is quite commonly done with the aid of computers, and in many cases the experiment itself is performed under the control of a computer which reduces and analyzes the data during the experiment. As examples, I am thinking of studies of the structure of complex protein molecules with X-ray crystallography, some of the elegant experiments of high-energy physics, and the very public experiments conducted by NASA on the moon. There are even computer programs which will perform mathematician's "experiments," by proving mathematical theorems,[2] much as you and I were asked to do when we studied Euclid's geometry in school. As to writing up the results, at our Laboratory, for some publications we do use graphs prepared entirely by a computer-driven plotter. I know of no instance where a journal publication was written entirely by a computer, although some papers may read as if they were.

It is in applied science, however, and even more so, in engineering, that today's computer comes into its own. It is a powerful tool for performing exacting and tedious jobs, such as the computations involved in designing bridges, ships, and aircraft. Engineering drawings are prepared by computer in many shops. Meteorologists use forecasts prepared entirely by computers for the Northern Hemisphere. The computer does the job in an hour or two. I doubt that such numerical forecasting computations could ever be done manually, because of errors which occur when people do the calculations; but if it could, it would take a large group of technicians more than a year.

Engineers, then, make the most extensive use of computers, followed by the applied scientists. On the whole, scientists engaged in basic research tend, I think, to make the least use of computers, although there are a large number of important exceptions. It is no accident, however, that some of the outstanding exceptions occur at MIT, where basic researchers work side by side with applied scientists and engineers.

The relative degree of creativity and originality required in engineering, applied research, and basic research is only part of the reason for these differences in the impact which computers have had on physical science. Another related reason can be phrased in a rather outrageous but instructive way: the basic researcher is in the business of making mistakes, while the engineer is in the business of avoiding them. Applied science lies somewhere between.

The engineer's interest in avoiding mistakes is obvious. He tries to deal in certainties, using the best understood materials and techniques, in the best possible way, to make sure that his building will stand, his ship will float, and his airplane will fly. He is also interested in doing all this at minimum cost. For him, mistakes can be expensive; for his clients, they can be fatal.

The basic researcher's interest in making mistakes is less obvious, but quite real. Instead of dealing with certainties, he deals with, and tries to explore, the unknown. And he does this mainly by a process of elimination. Any number of explanations can be advanced when one tries to explain new phenomena; the researcher's job is to devise experiments which eliminate as many false guesses as possible.[3] He sets up hypotheses, preferably of the "either-or" type, and then tries to design an experiment that will determine conclusively which of the alternatives is mistaken. It is this kind of controlled mistake I referred to when I said that basic research is in the business of making mistakes. It does so in order to learn from them.

From this rather unusual point of view, the computer's virtue and major flaw is the fact that it makes almost no mistakes at all. This is ideal for the engineer, which explains why he likes to use computers. A tool which does not make mistakes is just as useful to the scientist, of course, and he uses computers as often as he can to save himself time and trouble. But, unlike some engineers, he is not in partnership with his computer, in any sense of the word. At least, not yet.

Which brings me to the major theme of my talk today. I believe that the true impact of computers on science—basic research, if you prefer—will result from our ability to make the computer behave as a partner instead of as a tool, as an active participant instead of as a sort of electronic slide rule.[4]

Let me give you some examples of this type of partnership as it exists today. Many of the theories of physics can be stated in extremely general and powerful terms by means of mathematical equations. Because these equations are so general, one set of equations can be used to examine a large range of problems. The equations of hydrodynamics, for example, describe every possible type of motion which a fluid can undergo; the transmission of sound or pressure waves; the pulsations of a raindrop as it forms in a cloud, falls through the air, and finally hits a surface with a splash; the response of the sea surface to a storm, including the movements of waves from the time they are generated until they reach Waikiki to break up in foam. These equations can also describe all the movements of the atmosphere, or, if we include the effects of gravitational attraction in the proper manner, they can describe the vast fluid movements of a galaxy. Unfortunately, although these difficult equations are capable of doing these things, we do not know enough about the methods of solving them to obtain solutions for any but the simplest cases in the classical analytical manner. Nor do we always know enough about the physical systems which the equations represent to be sure that our mathematical solutions are correct. It has been known for a long time that we can solve equations by brute force numerical calculations when more elegant methods are lacking, but the brute force required is usually so great that it might have taken years and years of manual computation to arrive at a solution. But now we have just the kind of help required for this job: a patient, vastly accurate, and extremely fast machine, the computer.

An experiment conducted by Shannon and Fromm of the Los Alamos Scientific Laboratory showed a beautiful example of such a brute force solution to the equations of hydrodynamics.[5] Every detail of water flowing over a cliff was examined, its speed at every point in space and time, the internal pressure distribution, even the details of the turbulence at the bottom were examined by making the computational resolution much finer than the structure of the turbulence—at considerable extra cost in increased computer time. Similar solutions have been obtained for drops of water splashing on water, for breaking waves, for the transfer of heat from an obstacle to water flowing past it, and a number of other related problems.

There are two points to note: First, every variable is under control in such a computer experiment. One could, for example, change one number in a program and thus solve this problem for the case where there is no gravity, as in a satellite, or for the case where gravity is 10 or 1,000 times as great as it is here on earth. Try that in the laboratory! Or, make another change in a single number, and one could change the viscosity or density of the fluid from that of water to that of gasoline, tar, or any other possible or impossible fluid.

The second point to note is the fact that such computer experimentation, which is called "modeling,"[6] is exorbitantly demanding for the scientist and for the programmer. For the scientist, because he has to know what he is doing, to a degree which is almost incredible; and for the programmer, who has to get every instruction, every comma and decimal place, every last detail, exactly right. My assistant and I have worked, sporadically, on a similar fluid flow program for something over a year, and I speak from painful experience. Not only do the equations have to be exactly correct, and in terms the machine can use efficiently, but every detail of the boundary and initial conditions has to be worked out, and the program has to be completely consistent internally. Simply stated, the waterfall problem had to be set up in such a way that the amount of water entering equals, to perhaps 6 decimal places, the amount accumulating inside the frame plus the amount leaving.

Perhaps I have belabored the point somewhat, but I wanted to make it as clear as possible that the computer promises to force us to refine our thinking processes to a degree which itself amounts to a revolution.

A concrete example: Kepler set out in 1601 to compute the orbit of Mars.[7] He bet that he could do it in one week. It took him the better part of four years. And 900 pages of his notebook are devoted to the calculations. About three years ago, Gingerich set up Kepler's procedure for solution on a computer. It took a month or so to get the problem programmed, and eight seconds to solve it. In the process, Gingerich found that Kepler had begun his work by making mistakes in three out of his eight initial values. He also found that the computer solved the problem in nine iterations, whereas poor Kepler had to go through 70 iterations before he got consistent values. Why? Because he made mistakes, which produced errors in his answers, which had to be smoothed out by several added iterations each time. Fortunately, Kepler had chosen his method well, so that it was able to converge on the correct or nearly correct values. It is interesting to speculate about the results if anyone less meticulous than Kepler had tackled the problem. The moral, if there is any, is that being human, we make mistakes, and that there must be quite a number of human mistakes buried in the bones of present-day science which we know nothing about. In the case of the viscous fluid flow program, I can testify that it is literally impossible to check the computer's results by hand, because it is impossible to perform the required several thousand calculations without making errors of the most trivial kind, but entirely significant enough to ruin the manual results. They will never agree exactly with those obtained by the computer except by merest chance.

In fields which are less mechanistic than hydrodynamics, it is still possible to perform experiments with a computer. Holling, for example, uses such experiments to study predator-prey relationships.[8] He does this by breaking down the patterns of behavior of his idealized animals into well-defined units, expressing by a simple equation the way in which each part of the total behavior-pattern responds to changes in other factors. He allows the computer to keep track of these parts, and adds them together under various sets of rules, to synthesize a total behavior-pattern. To simplify somewhat, consider a predator which starts to search for food when it gets hungry, detects its prey at some given average distance, has some postulated probability of catching an individual prey organism in each attempt, takes a certain period of time to eat its prey, and then another period of time to digest it and become hungry again. Each step–digestion, search, chase, capture, eating, and digestion again–takes an amount of time which varies with such factors as the prey density, the relative size of predator and prey, and the probability of capture per attack. All of these can be programmed, under a variety of assumptions, and the total time for each cycle can then be calculated. Under certain assumptions, even this simple model predator can show considerable changes in behavior in response to changes in prey density, which can be held fixed, or allowed to drop with predation, or to decrease due to natural mortality plus predation, and so on. In Holling's case, one can even say that the computer program *is* the theory. Backed by appropriate experiments–which the model helps define, by the way–such models can be powerful tools for increasing our understanding of the world around us.

To summarize, man-machine partnerships can help to supplement man's creative abilities by helping him to explore his problems in depth, from various angles, weighing alternatives in terms of their consequences, at vastly greater levels of complexity and detail than ever before. Conventional uses of computers as tools will most certainly continue to grow, particularly in the more applied areas of science. But the real impact is yet to come, and it should see man concentrating on what he does best, freed by the computer from the obstacles and drudgery of mental labor.

What can we expect will come of this? First, let us look at our prospective partners, and then at our problem areas, to see how we might put them together.

In studying a typical modern computer center layout, we note that the heart of the computer, its central processor and memory is only a small part of the whole. All the other units–magnetic tape drives, card-reader and punch, printer, typewriter, and video screen–are input/output devices.

Man is rapidly becoming the single dominant factor in his environment, which he understands only in a fragmentary way. With the power of large computer complexes, large libraries immediately available for reference, and with field data collected in the light of preliminary model experiments, our knowledge of first, second, and higher order interactions may make it possible to consider entire complexes of problems together. When a farmer fertilizes his fields, he may do so knowing that x pounds of fertilizer per acre may produce optimum yields this year, but suboptimum yields for two following years, a 25 per cent decrease in the population of one plant pest, increase in the rate of development of one species of weed but inhibition of three other species; that it would create a requirement for certain feed supplements for the animals he plans to feed with his crop, and, with more accurate weather forecasts, or even partial control of weather, he can even select from a choice of optimum dates for his operation. Hundreds of thousands of similar decisions, transmitted (without information which the farmer regards as privileged) to central files, and correlated with other pertinent data, would result in much improved crop forecasts, stabler market prices for crops and animals, changes in published figures for demand for transport six months hence, and even in changes in the timing of traffic lights at proper times of the year to allow for changes in traffic resulting from the flow of farm products to the market. Far from being rigid, this system could be revised on a daily basis, allowing for a variety of emergencies and unforseen circumstances.

Such a system would respond to individual requests for information and action. In planning a trip, for example, one could specify the starting and end points, and allow the system to present a set of optimum routes and timetables, complete with reservations–all of which could be changed hour by hour if need be. Work could be performed anywhere, with the results transmitted anywhere else, to wait until they are needed, or to call for immediate attention if that is what is required.

In short, the impact of the computer on science, and on man's daily world, will almost certainly be greater than the cumulative impact of everything which has gone before, from the industrial revolution to the discovery of atomic power, because of the generality, speed, and accuracy of the computer. The only real limit in sight is that imposed by man's wisdom and imagination, because in the last analysis, nothing can be done by any computer which has not originated in man's mind. And the computer will impose a discipline of its own on man's thinking, which will be stretched and given new perspective by the man-machine partnership.

Wise legislation will doubtless be needed to protect our rights and our privacy, and we may even see a new lay priesthood arise from those who can communicate with machines, a priesthood sworn to silence, to keep from revealing what they, like doctors or lawyers, may learn in the performance of their duties.

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(1) Barkley, Richard A.*: Is the boundary between the Kuroshio and Oyashio a compound vortex street?

Abstract: The boundary between the Kuroshio and Oyashio can often be accurately described by a simple kinematic model consisting of two parallel vortex streets. The two are usually out of phase, resulting in a boundary which is alternately wide and narrow. At other times the two vortex streets appear to be in phase and merged into a single, more intense, vortex street, resulting in a uniformly narrow boundary. Internal velocity shear (and therefore friction) is at a minimum only when the vortex streets are exactly in or out of phase. This fact may account for the tendency of the system to assume only two configurations. The well-known cold cyclonic eddy of the Kuroshio off southern Honshu seems to occur only when the two vortex streets are out of phase. The wavelength of the system is approximately 220 nautical miles. Observed oceanographic phenomena off the east coast of Japan agree well with the theory.

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Reprinted from COPEIA 1967, No. 2 June 5
pp. 441–451

Age, Growth, and Reproduction of the Dolphin, *Coryphaena hippurus,* in the Straits of Florida[1]

GRANT L. BEARDSLEY, JR.

The dolphin grows rapidly throughout its life. Check marks believed to be annuli were formed from November through February. Average growth was 725 mm fork length the first year and 450 mm the second year. One older fish belonged to age-group III (1425 mm long), and another to age-group IV (1525 mm). A male dolphin in the reef tank of the Miami Seaquarium, Miami, Florida, grew from about 0.5 kg (one lb.) to 16.3 kg (36 lb.) in about eight months. Maximum life span is probably about four years. Male dolphin longer than about 450 mm were heavier than females of the same length.

Reproduction was studied by gross observation of the gonads, measurements of egg diameters, and counts of maturing eggs. Changes in the gonads through the year indicated that the spawning season in the Florida Current extends from November through July and is at its peak in March. Female dolphin begin to mature at 350 mm fork length, and all are mature by 550 mm. Males begin to mature at a slightly larger size. Female dolphin produce 80,000–1,000,000 eggs at each spawning and spawn twice (perhaps as many as three times) per year.

INTRODUCTION

THE dolphin, *Coryphaena hippurus* Linnaeus, is a pelagic fish, widely distributed throughout the tropical and subtropical waters of the world: it has been recorded as far north as Nova Scotia (ca. lat. 45° N., Vladykov and McKenzie, 1935) and as far south as the southern tip of Africa (ca. lat. 35° S., Barnard, 1927). It is a valuable commercial species in Japan, China, and the Hawaiian Islands, and is an important source of food in many of the islands of the Pacific and Caribbean. It is an important sport fish in Florida and is taken on more trips and in greater numbers by Florida east-coast charterboats than any other species (Ellis, 1957).

In the Florida Current the dolphin is a top-level predator and an important member of the *Sargassum* community. That dolphin feed on other members of the community to a large degree is readily demonstrated by the stomach contents. Gibbs and Collette (1959) examined the stomachs of 46 dolphin from the Gulf Stream and found specimens of Balistidae in 22 stomachs and Carangidae in seven. Both families are common in the *Sargassum* fauna. Thirteen stomachs contained crabs, also common in *Sargassum,* and eight contained fragments of *Sargassum.* Although I did not study food habits, superficial examination of numerous stomachs during more than a year of sampling confirmed the findings of Gibbs and Collette.

Dolphins tend to be closely associated with floating and drifting objects on the high seas. During the spring and summer in the Florida Current, charterboat captains know that any floating log, plank, or large patch of *Sargassum* is almost sure to shelter dolphins. One captain reported taking seven 4.5–5.4 kg (10–12 lb.) dolphin from under a small plank about one m long and 15 cm wide. On 31 July 1963, five boats took more than 700 dolphins from beneath a large windrow of *Sargassum* about 8 km from the western edge of the Florida Current. Kojima (1956) suggested that dolphins take shelter under floating objects because of the greater availability of food there, and that they leave only when food is plentiful nearby.

Charterboats from Miami often "chum" a school to the stern of the boat and hold the fish there until almost all are caught. Some captains leave one dolphin on the line in the water because they believe it is a lure to others in the school. The fish show no fear of the boat and bite readily on almost any lure or bait. It is noticeably more difficult, however, to chum the larger fish; only the

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[1] Contribution No. 788 from the Institute of Marine Science, University of Miami. This paper is based on a thesis submitted to the University of Miami in partial fulfillment of the requirements for the degree of Master of Science.

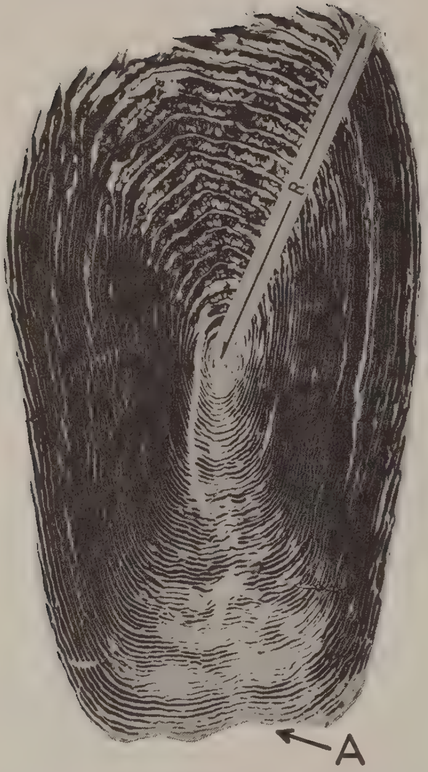

Fig. 1. Scale impression from a male dolphin (age-group 0), 686 mm FL, captured 23 Aug. 1963. R, scale radius. A, anterior edge.

small dolphin 300–500 mm long (commonly called "school" dolphin) can be chummed consistently.

Materials and Methods

Dolphin samples came from three main sources: the charterboat fleet at Pier 5, Miami, Florida; Al Pflueger, Inc. (taxidermist); and my own collecting trips. Because dolphins are highly desirable food fish, the charterboat crews clean the fish immediately after docking and sell them directly to customers on the docks. This custom made it necessary to collect data on each fish rapidly.

I examined scales from 511 dolphins. Scales were taken from an area just above the lateral line behind the tip of the pectoral fin. Preliminary examination of scales taken from various parts of the body indicated that this area provided uniform, well-marked scales. Ten to 15 scales from each fish were stored in labeled styrene vials filled with water. Two or three drops of 10% phenol were added to each vial to retard bacterial action. Date of capture, fork length, sex, and other pertinent information were recorded, and each vial was given a code number.

The scales were prepared for reading by making impressions in plastic. The scales were mounted, sculptured side down, on 42-mm sheets of cellulose acetate, 0.5 mm thick. Usually 8–10 scales from one fish were mounted on each slide, without cleaning or other preparation. The slides were then placed between two stainless steel plates and subjected for 5–8 sec to 6 tons of pressure at 75° C in a Carver Laminating Press. (Fred S. Carver, Inc., Summit, New Jersey.)

The scale impressions were examined with a binocular microscope at a magnification of 60 diameters. The resulting image was clear, and the circuli, annuli, and other features of the scale were well defined. Scales were measured with an ocular micrometer. All measurements were along a line separating the posterior field from the lateral field (Fig. 1). The most symmetrical scale on the slide was chosen for measurement. Age groups were classified according to the number of annuli present. Fish with no annuli were designated age-group 0. All fish-length measurements are given as fork length.

Maturity and spawning of the dolphin were studied by two methods: gross examination of the gonads, and determination of frequencies of ova diameters. All dolphins were assigned a maturity stage according to the criteria established for this study. Ovaries of 85 fish were removed, intact when possible, placed in small, labeled cloth bags, and preserved in 10% formalin. The samples were not random but were taken to cover a wide range of fish size and to represent all developmental stages.

To test the size distribution of eggs within the ovary, samples were taken from the anterior, central, and posterior sections of a mature ovary, and 250 eggs were measured from each sample. Differences in the size and position of the modes were not significant; most subsequent samples were taken from the center of the ovary. A formalin–preserved sample was compared with a fresh sample to learn the effect of the preservative on the size of the eggs. A slight shrinkage was evident, but since all samples were preserved in the same manner, shrinkage was not considered to affect the results. Samples of 100, 200, 250, 300, 400 and 500 eggs were measured, and the resulting frequencies compared. Above a sample size of 200 eggs, the relative position and elevation of the modes did not differ; all subsequent measurements were made on samples of 250 eggs.

The eggs were measured with an ocular micrometer in a compound microscope. Dolphin eggs are roughly spherical, and all eggs were measured with the micrometer horizontal in the eyepiece regardless of the position of the eggs. Only eggs measuring 10 micrometer units (0.363 mm) or more were recorded. Eggs smaller than this made up the vast supply of immature eggs that are present in the ovary throughout most of the year.

Age and Growth

The scale.—Dolphin have thin, cycloid scales. The general shape is rectangular to oval. The outer surface of the scale bears concentric ridges or circuli arranged about a focus. Many of the circuli in the anterior and lateral fields are discontinued at the edge of the posterior field. Circuli that do continue through the posterior field are heavier than at any other place and are widely spaced. The scales are firmly anchored in the scale pockets and are difficult to remove; regeneration is accordingly uncommon. Squamation of the body is complete; only the head and fins lack scales.

Scales first appear when the dolphin is 100–120 mm FL as minute platelets imbedded in rows of scale pockets on the caudal peduncle. When the fish are 180 mm FL, the scales are easily visible under magnification. They have 10–12 circuli and a radius of about 0.5 mm. At a fish length of 200 mm the posterior portions of the scales begin to break through the integument; they then have about 14–18 circuli and a radius of about 0.7 mm.

The annulus.—No description of the annulus on dolphin scales appears in the literature. Schuck (1951) and Williams and Newell (1957) were unable to find annular markings, and no other indication appears in the literature that any attempt has been made to determine the characteristics of the yearmark.

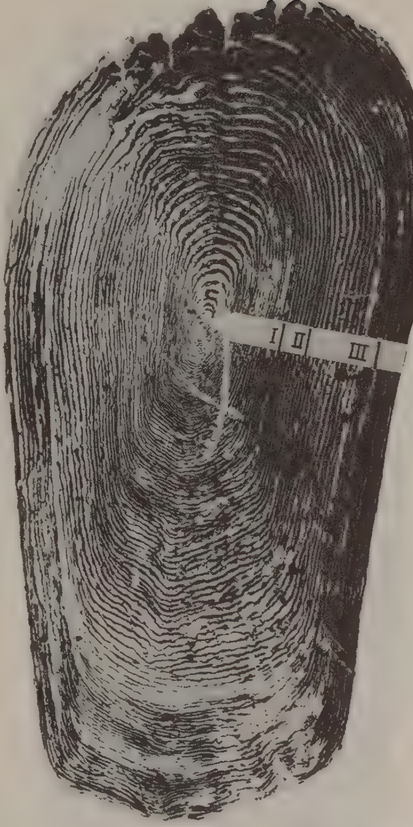

Fig. 2. Scale impression from a male dolphin (age-group III), 1425 mm FL, captured 17 Feb. 1964. The three annuli demonstrate the abrupt narrowing, then widening of the circuli, a common feature of the annulus.

I believe the check marks on dolphin scales to be true annuli for the following reasons: (1) there is a correlation between the size of the fish and the number of annuli, (2) there is a steady increase in the width of the marginal increment between the last annulus and the margin of the scale in fish caught from November through October, (3) the check is formed at approximately the same time each year, (4) for a given fish the marks are formed on all normal scales of the fish and the course of the annulus is traceable around the sculptured part of the scale.

Three features of dolphin scales serve as principal indicators of the annulus: spacing of the circuli, broken and generally disrupted circuli, and the cutting-over in the posterolateral field which has been described frequently for other species.

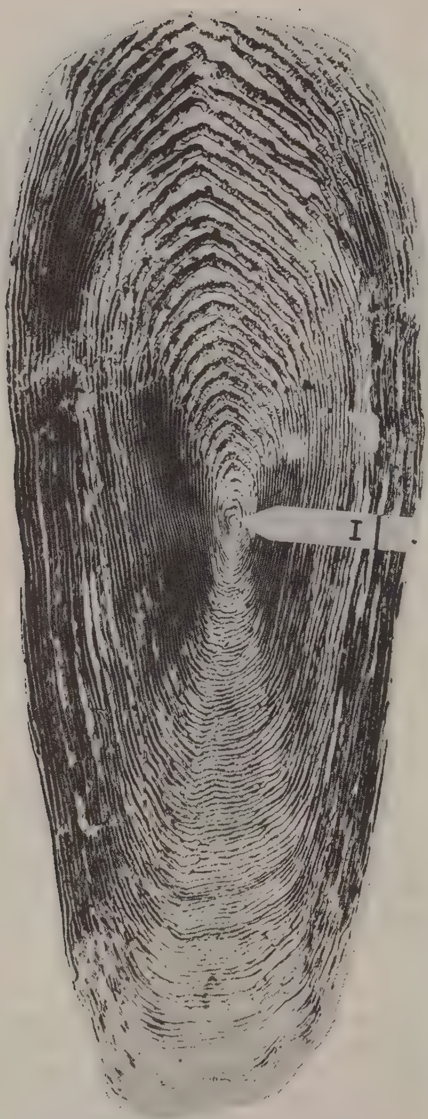

Fig. 3. Scale impression from a female dolphin (age-group I), 1160 mm FL, captured 4 Dec. 1962. The annulus shows the splitting and disrupting of the circuli present on many scales.

The most common and useful indication of an annulus on dolphin scales is the abrupt narrowing and then widening of the spacing between the circuli. These narrowly spaced circuli form a narrow band of from three to five circuli that extends through the anterior field and both lateral fields. This feature is present in almost all year-marks. The third annulus on the scale in Fig. 2 shows this pattern clearly. Where this narrow band of circuli enters the posterior field, it often dips towards the center of the scale, cutting across circuli that are inside the annulus.

Although the narrow band of circuli is the most reliable indicator of an annulus on dolphin scales, it is frequently accompanied by other evidence. A common feature is a splitting, anastomosing, and general disruption of the even pattern of the circuli. This disruption continues for about five or six circuli before the even and equal spacing begins again. The circuli within this disrupted area are often thin, discontinuous lines, which often touch each other. Fig. 3 shows a scale in which this disruption of the circuli is evident; the annulus is readily traceable through the anterior field.

The third common feature of the annulus, the cutting-over of the circuli in the posterolateral field, has been described for other fishes so frequently that it is not necessary to review it here. It is fairly common on dolphin scales and is easily recognizable when present.

The annulus first forms on the anterolateral borders of the scale. It is first seen as a crowding of the circuli at the anterior corners. As scale growth continues, this narrow band of circuli extends posteriorly through the lateral fields until it reaches the posterior field. By this time, new growth beyond the annulus is evident at the anterior corners. A year-mark was not assigned unless this narrow band of circuli was traceable through the anterior field and both lateral fields.

Agreement between readings.—The scales were read twice, the readings spaced far enough apart to prevent bias from the first examination. The two readings agreed for 85% of the fish. A tendency existed during the first reading to place annuli where none existed, particularly for the larger fish. The second examination lowered the estimate of age for 30 fish and increased it for 18. Any scale for which the readings were different was examined a third time, and a final decision made as to the age. In all but three fish the final decision agreed with the second reading. The general agreement in readings indicated that accuracy of annulus determination improved with time and experience.

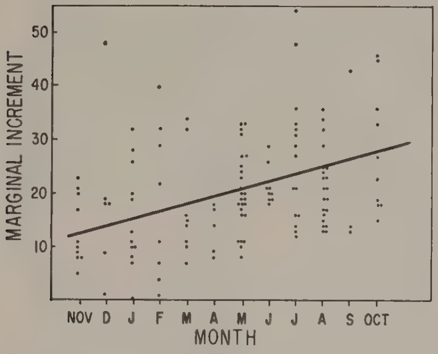

Fig. 4. Scatter diagram of increase in width of marginal increment on dolphin scales Nov. through Oct. The formula $I = 10.6323 + 1.4255t$ describes the straight line. (Marginal increments in micrometer units (1 unit = 0.0182 mm).)

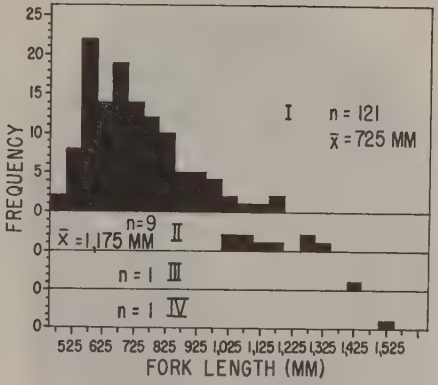

Fig. 5. Length-frequency distribution of four age groups (excluding age-group 0) of dolphin collected off Florida. (Number of fish represented indicated on figure.)

Annulus formation.—To determine the time of year when the annuli on dolphin scales are formed, the distance between the last annulus and the margin of the scale was measured for all scales with one or more year-marks. Included were nine fish with two year-marks, one with three, and one with four. Although the inclusion of these older fish does admit some heterogeneity into the data, it does not seriously affect the results because of the rapid growth of the dolphin. These data are presented as a scatter diagram of marginal increments (Fig. 4). Marginal growth clearly was variable for all 12 months. This variability reflects individual differences in the time of onset of growth and in rate of growth in the season the increment was laid down. Only during December, January, and February did any scales show marginal growth of less than 0.0546 mm (three micrometer units). Marginal growth was greatest in October. Although November samples did not include any fish with growth increments on the scales of less than 0.0546 mm, this month was taken as the beginning of the period of annulus formation because of the abrupt decrease in the width of the increments from October to November.

Because of the wide variation in marginal growth in any given month and the small size of the sample, the increase in the width of the marginal increments from November through October was not readily apparent. To test the validity of this assumed increase a regression line was calculated on the data from November through October (Fig. 4). The straight-line formula is $I = 10.6323 + 1.4255t$, where I is the marginal increment and t is time. The slope of the line indicated a significant increase in marginal width on the scales from November through October (t test: $\alpha = 0.05$). The actual rate of increase may have been greater than the line suggests. Some of the larger increments in the earlier months of the period may have represented the full-season growth of fish that had not yet completed the annulus.

Numerous factors have been suggested as the cause of annular rings on fish scales—temperature, availability of food, and physiological stress are commonly cited. Temperature has commonly been accepted as a major factor. Chevey (1933) believed that a temperature change of from 4° to 5° C was sufficient to cause annulus formation in tropical fishes. The mean annual temperature change in the Florida Current, according to Fuglister (1947), is about 5° C. The abundance of food for dolphin in the Florida Current apparently changes little during the year. I observed scant change in the quantity of food in dolphin stomachs between winter and summer. Gibbs and Collette (1959) found no empty stomachs in a sample of 30 dolphins taken in June from the Gulf Stream and only one in a sample of 10 captured during the fall. The period of annulus formation for the dolphin coincides with the beginning of the spawning season. Scale samples from 18 females which were classified as ripe by gross examination, however, showed no recently formed annuli. Further-

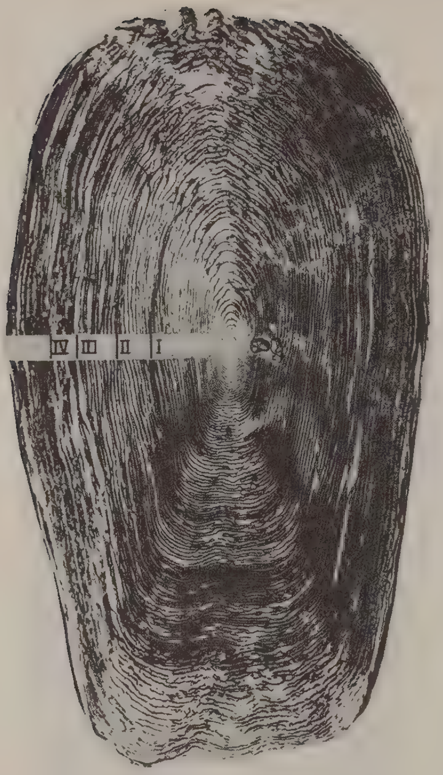

Fig. 6. Scale impression from a male dolphin (age-group IV), 1525 mm FL, captured at Bimini, Bahamas, June 1964. This fish weighed 34.8 kg (76 lb., 12 oz.) and is a new all-tackle world record.

more, annulus formation is complete by March, the month of peak spawning. Evidence indicates that the formation of the annulus on the dolphin scales is correlated with a temperature reduction in the Florida Current in the winter.

Growth.—Dolphins grow very rapidly (Fig. 5). The most striking feature about the growth is the wide size range of yearling dolphin. This scatter is believed to result from the extended spawning season of the species, discussed in a later section. Fish which hatched from eggs laid at the beginning of the spawning season have a six or seven month longer growth period before forming an annulus than fish that hatch near the end of the spawning season.

Rapid growth is also evident in fish kept in large aquaria. Herald (1961) reported that at Marine Studios, Marineland, Florida, two dolphin grew from about 0.7 kg (1.5 lbs.) to 14.5 kg and 16.8 kg (32 and 37 lbs.) in 7½ months. In the present study a dolphin placed in the reef tank at the Seaquarium, Miami, Florida, in September 1963, at a length of less than 400 mm and a weight of about 500 g, weighed 16.3 kg and measured 1060 mm on April 1964, or about eight months later.

The life span of the dolphin appears to be short. During this study only 11 fish were found with two or more annuli. Five females and four males were in age-group II, one male was in age-group III, and one male in age-group IV. The four year old fish (Fig. 6) caught off Bimini, Bahamas, in June 1964 weighed 34.8 kg (76 lb., 12 oz) and was 1525 mm long (a new all-tackle world record).

First-year growth in length is particularly rapid, averaging 725 mm (Fig. 5). Second-year growth averages 450 mm. For a given age males appear to be larger than females. Of the nine fish with two annuli, five were females and four were males. The length of the males ranged from 1150 mm to 1325 mm ($\bar{x}$, 1255 mm), and the females ranged from 1002 mm to 1145 mm ($\bar{x}$, 1084 mm).

Increase in weight is also rapid. The average weight was about 5.9 kg (13 lb.) for fish with one annulus and 12.5 kg (27½ lb.) for fish with two annuli. The III-group fish weighed 25.4 kg (56 lb.) and the IV-group fish weighed 34.8 kg (76¾ lb).

Length-weight.—Fork length was plotted against weight for 40 females and 19 males (Fig. 7). The equation expressing the length-weight relation for the males is $W = 2.62 \times 10^{-4}L^{2.66570}$ and for the females, $W = 2.35 \times 10^{-4}L^{2.62796}$. The fitted curves suggest that males were heavier than females at all lengths down to about 450 mm, the lower limit of the data. This difference in weight for a given length seemed to increase gradually with increase in length.

REPRODUCTION

Several authors (Schuck, 1951; Erdman, 1956; Williams and Newell, 1957; and Gibbs and Collette, 1959) reported briefly on spawning in the dolphin. Most of these reports, however, dealt with fairly small samples, and did not describe the reproductive stages of the gonads, delineate the spawning season, or discuss other important aspects of the reproduction of the dolphin.

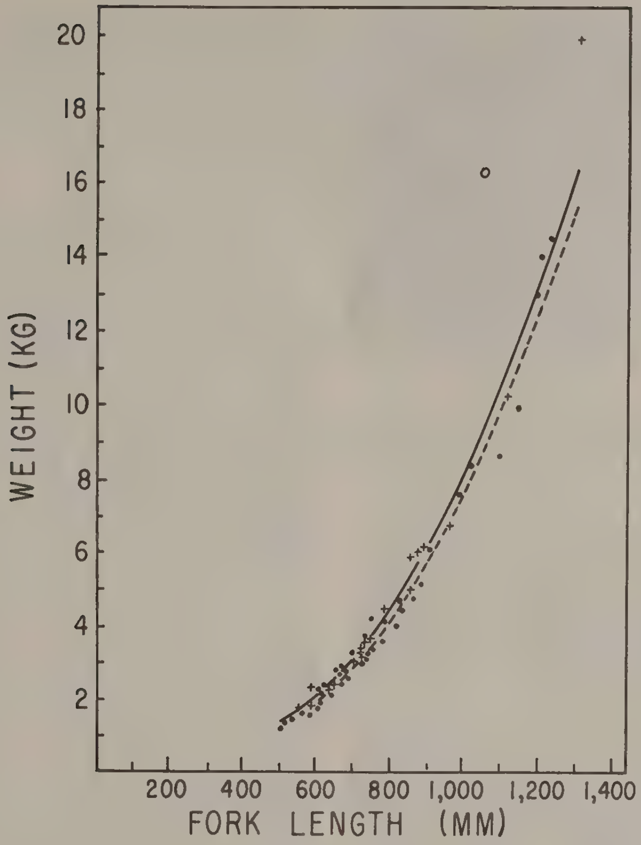

Fig. 7. Length-weight relation of 59 dolphin from the Florida Current. Crosses and the solid line represent males (n = 19); dots and broken line, females (n = 40). Open circle, upper right, represents a male dolphin reared for almost eight months in a large aquarium (not included in the length-weight calculation).

Description of the gonads.—The testes of immature fish are thin and unbroken, but the testes of mature males are marked with deep fissures which give a segmented appearance. The diameter of the ovaries is 3–4 mm in immature females and increases at maturity to 40–50 mm. The lumen extends the length of the ovary, opening to the exterior through a short oviduct and urogenital orifice. The ovaries unite posteriorly; the left ovary is slightly the longer.

On the basis of gross examination, I classified the ovaries into the following maturity stages:

I Immature. Ovaries long, thin, hollow tubes; diameter, 3–4 mm, eggs microscopic; ovary wine-red to pink.

II Early Maturing. Ovary slightly enlarged; diameter, 10–15 mm; eggs visible to the naked eye through the ovary wall, but no distinct size groups distinguishable; pale yellow.

III Late Maturing. Ovary much enlarged; at least two distinct size groups of eggs easily visible to the naked eye; bright yellow to orange.

IV Ripe. Ovary distended, half filling the body cavity; lumen full of large, clear eggs which give the ovary a speckled appearance.

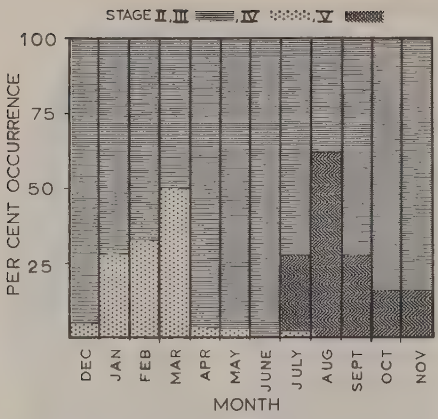

Fig. 8. Percentage occurrence of female dolphin with gonads in stage II or III (maturing), stage IV (mature), and stage V (spent).

V Spent. Ovaries flaccid, hollow tubes; a few remnants of ripe ova may remain in the lumen or folds of the ovary, usually visible by microscopic examination; dull red and discolored, particularly at the posterior end; numerous blood clots.

I saw no fish in the running-ripe stage. Williams and Newell (1957) included this stage, although they did not observe the condition in females from East African waters.

Microscopic examination of numerous stage–III ovaries made it evident that several females had recently spawned. The ovary was almost hollow, and several mature ova were in the lumen and folds of the ovary. Females with stage–III ovaries, therefore, included females that had spawned previously in the season of capture and those that had not yet spawned. Fish with stage–V ovaries had finished spawning; their appearance in the catch signified the end of the spawning season.

Fish with stage–IV ovaries are ready to spawn. This stage begins with the appearance of a few mature, translucent eggs. As maturation progresses, the number of mature eggs increases until the ovary is distended with ripe eggs. Any fish with mature, clear eggs visible through the ovary wall was classified as having stage–IV ovaries.

The testes were not classified in the same manner as the ovaries because seasonal changes in maturity could not be detected visually. Otsu and Uchida (1959) found the same situation in the albacore, *Thunnus alalunga*, and classified the males only according to the size of the testes and the presence or absence of milt. This procedure, adopted for this study, gave the following two stages for the testes:

I Immature or Resting. Testes small, firm to the touch; no milt extruded after cutting and squeezing.
II Mature. Testes enlarged; milt extruded after cutting and squeezing.

Williams and Newell (1957) listed five stages for males but indicated that the immature (their stage I) and mature-spent (stage V) were not seen. Spawning seems to be prolonged, and multiple spawning may be common among both males and females.

Time of spawning.—Dolphins have an extended spawning season. The percentage of ripe (stage IV) fish in the samples indicated peak spawning from January through March (Fig. 8). Although no ripe dolphin were found in the samples in November, microscopic examination of the ovaries of several females showed residual mature eggs in the lumen of the ovaries that indicated previous spawning. No ripe females were found in June, although one was taken in May and one in July. Schuck (1951) stated that off the North Carolina coast in May and June, he observed dolphin that appeared to be ripe, and Gibbs and Collette (1959) reported that dolphin caught in the Gulf Stream in June were ripe or nearly ripe. Because recently spawned females were found in November, and some females reach full maturity in the Florida Current in the summer, the spawning season extends over nine months; peak spawning is in January, February, and March.

The occurrence of the young in the Florida Current indicates that spawning may be almost year-round. Gibbs and Collette (1959) found young dolphin in the Florida Current at all seasons of the year but at peak abundance during the summer. The collection of small (under 10 cm) dolphin at the Institute of Marine Science, the University of Miami, contains specimens taken from November through May, and in August. John Casey, of the Bureau of Sport Fisheries and Wildlife, Sandy Hook Marine Laboratory, reported (pers. comm.) numerous small (4–5 inch) dolphin off the North Carolina coast

TABLE 1. NUMBERS OF FEMALE DOLPHIN AT DIFFERENT STAGES OF MATURITY IN DIFFERENT MONTHS IN THE FLORIDA CURRENT, 1963–64. (See text for description of stages.)

Stage	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
I	10	3	11	16	4	14	32	21	2	14	1	–
II	5	2	4	10	3	3	28	37	6	17	–	–
III	29	9	12	27	67	44	55	45	11	31	27	21
IV	12	5	17	2	1	–	1	–	–	–	–	1
V	–	–	–	–	–	–	17	76	4	6	5	–
Total	56	19	44	55	75	61	133	179	23	68	33	22

from July to September. Rose (1965) found large numbers of females with ripe ovaries in the Gulf Stream off Hatteras, N. C., in June and July.

The sudden appearance of spent (stage V) fish in the samples in July (Table 1), three months after the end of peak spawning (March), may have been caused by the bulk of the spawning population moving out of the sampling area after March, to be replaced by a new group of fish in July that had completed spawning, possibly in another area.

Information on the migration of dolphin is scant. Large groups of school dolphin have been reported to follow *Sargassum* concentrations northward from the lower Florida Keys to Palm Beach, a distance of about 370 km. Frank Mather, III, of the Woods Hole Oceanographic Institution, reported (pers. comm.) that a dolphin tagged off Marathon, Fla., was recaptured 56 days later off Hillsboro Inlet, Fla., 260 km to the north. The possibility is strong, therefore, that dolphin migrate northward during the spring and summer, and that the spawning and spent groups in the samples represent two separate populations.

Multiple spawnings.—The size distribution of eggs from mature dolphin during the winter and spring suggests that dolphin spawn more than once during a single spawning season. At least two groups of eggs are present in the ovaries as eggs grow to maturity (Fig. 9). On the basis of position of the last mode, the following stages of eggs were assigned:

Immature
Stage A: Mode < 0.60 mm.
Maturing
Stage B: Mode, 0.60–0.69 mm.
Stage C: Mode, 0.70–0.79 mm.
Stage D: Mode, 0.80–0.89 mm.
Stage E: Mode, 0.90–0.99 mm.
Stage F: Mode, 1.00–1.09 mm.
Stage G: Mode, 1.10–1.19 mm.
Mature
Stage H: Mode, 1.20–1.29 mm.
Stage I: Mode, 1.30–1.39 mm.
Stage J: Mode, 1.40–1.49 mm.
Stage K: Mode, 1.50–1.59 mm.

Stage A represents immature fish and corresponds to stage I of the maturity stages assigned to the ovaries by gross examination. Likewise, stages B through G are maturing fish corresponding to stage II and III, and stages H through K represent mature fish corresponding to stage IV.

No time scale is represented in Fig. 9; the sequence of the fish was determined by the distribution of the eggs. The true time taken for eggs to grow from stage A to stage K is not known. No dolphin were found with more than two groups of eggs maturing at any one time. Stage B in Fig. 9 shows a group of eggs separating from the initial stock of immature eggs. This group continues to develop, and at stage F, when it has reached a modal size of about 1.0 mm, another group begins to separate from the initial stock and move towards maturity.

Further evidence of multiple spawning is seen in Fig. 10, which gives the ova-diameter frequency for a female dolphin captured 3 December 1962. Two groups of eggs are maturing, and remnants of large (1.5 mm diam), clear eggs were found in the lumen of the ovary.

It seems reasonable to assume that a dolphin lays more than one batch of eggs during a single spawning season. Fig. 10 and the presence of free eggs in the lumen suggest that as many as three groups of eggs are matured.

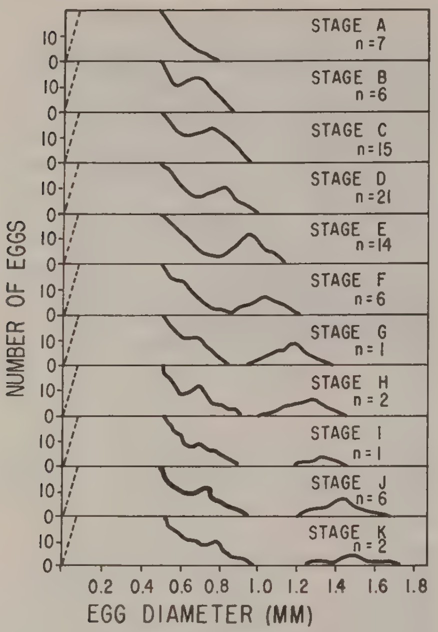

Fig. 9. Frequency of egg diameters of dolphin, showing growth of egg to maturity from top panel to bottom panel. Number of females included (n) is indicated at right of figure. Dotted line at left indicates immature eggs not measured. The data were smoothed once by a moving average of threes.

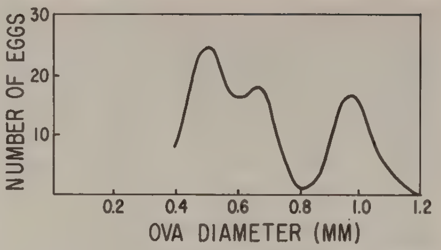

Fig. 10. Ova-diameter frequency of a dolphin with residual, translucent eggs in the ovary from a previous spawning (not included in the graph), and two groups of eggs that were progressing toward maturity.

Size at first maturity.—In the tabulation of the number and percentage of mature female dolphin at each 50 mm of fork length (Table 2), any female classified as stage II or more by gross examination was considered as mature. Female dolphin begin to mature at about 350 mm, 50% are mature at 450 mm, and 100% are mature by 550 mm. Because of the rapid growth and long spawning season, a female dolphin hatched at the beginning of the spawning season may grow to maturity and spawn before the end of the same spawning season.

The males were classified only according to the size of the gonads and the presence or absence of milt. The smallest male dolphin with milt was 427 mm long; eight dolphin in the 400–449 mm size group had milt. It appears that females may begin to mature at a slightly smaller size than males.

Fecundity.—Schuck (1951) estimated over six million eggs in a 8.4 kg dolphin taken off North Carolina. Because of the size of the estimate, it is believed that Schuck estimated the total number of eggs in the ovary. Beebe and Tee-Van (1928) estimated that a 2.7 kg dolphin contained a half-million eggs, and that about one third of these were noticeably larger than the rest.

Table 2. Number and Percentage of Mature Female Dolphin at Each 50 mm of Length. (All 315 females longer than 549 mm were mature.)

Fork length (mm)	Total No.	Mature (No.)	% Mature
300–349	4	0	0.0
350–399	14	1	7.1
400–449	73	23	31.5
450–499	132	81	61.4
500–549	128	119	93.0

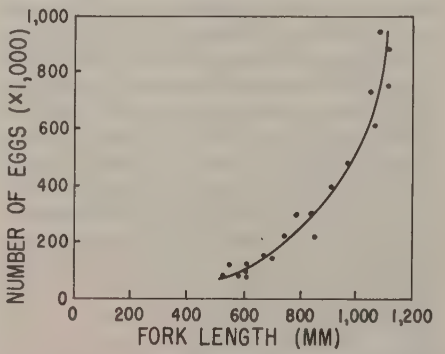

Fig. 11. Fecundity of 19 female dolphin. Each point represents number of eggs in most mature group in ovary (curve fitted by inspection).

In this study egg numbers were estimated for 19 females. The ovaries were removed intact and were treated with Gilson's fluid in the manner described by Simpson (1959). Only the largest group of eggs—those that would be released at the next spawning—was counted. Unless the eggs belonging to the most mature group could be distinguished readily from the other eggs in the sample, I discarded the ovary. After the eggs were free of all ovarian tissue, the liquid was decanted, and the remaining eggs were weighed on a beam balance to the nearest 0.1 g. A small sample was then weighed on an analytical balance to the nearest 0.1 mg and the most mature eggs in the sample were counted under a microscope. The total number of eggs in the ovary which belonged to the most mature group was then determined by simple proportion.

The estimates for dolphin (Fig. 11) indicate that, as in many other species, fecundity increases sharply with size. Since no conclusive information is available on the number of times a dolphin spawns each season, total annual egg production is not known. If three spawnings a year are assumed, annual egg production varies from about 240,000 to almost three million.

Acknowledgments

This study was supported in part by a Bureau of Commercial Fisheries Fellowship. At the Institute of Marine Science, University of Miami, C. P. Idyll supervised the project, and E. S. Iversen and D. P. de Sylva reviewed the paper. I thank Dr. Ralph Hile of the Bureau of Commercial Fisheries for his review of the manuscript. I also thank A. C. Jones, Assistant Director of the BCF Tropical Atlantic Biological Laboratory, who assisted with the statistical analysis; the captains and mates of the charterboat fleet at Pier 5, Miami, Fla. who allowed me to examine their catches; the Miami Seaquarium who permitted me to examine dolphin kept in their reef tank, and Al Pflueger, Jr., and his employees who provided additional samples.

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Bureau of Commercial Fisheries Tropical Atlantic Biological Laboratory, Miami, Florida 33149.

Reprinted from Great Lakes Fishery Commission,
Technical Report No. 12, September 1967

PHYSICAL LIMNOLOGY OF SAGINAW BAY, LAKE HURON[1]

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and Frank F. Hooper[3]

ABSTRACT

Water temperature and the distribution of various chemicals measured during surveys from June 7 to October 30, 1956, reflect a highly variable and rapidly changing circulation in Saginaw Bay, Lake Huron. The circulation is influenced strongly by local winds and by the stronger circulation of Lake Huron which frequently causes injections of lake water to the inner extremity of the bay. The circulation patterns determined at six times during 1956 reflect the general characteristics of a marine estuary of the northern hemisphere. The prevailing circulation was counterclockwise; the higher concentrations of solutes from the Saginaw River tended to flow and enter Lake Huron along the south shore; water from Lake Huron entered the northeast section of the bay and had a dominant influence on the water along the north shore of the bay.

The concentrations of major ions varied little with depth, but a decrease from the inner bay toward Lake Huron reflected the dilution of Saginaw River water as it moved out of the bay. Concentrations in the outer bay were not much greater than in Lake Huron proper. The proportions of various cations and anions were similar to the average proportions for the freshwaters of the world.

The average flushing time was 186 days, but was 113 days during the period of peak river discharge. The lakeward transport of Saginaw River water ranged from 619 to 2,294 feet per day in the inner bay to 1,410 to 3,000 feet per day in the outer bay on June 7 and October 30, respectively.

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Introduction

Bays are among the most productive environments of the Great Lakes. They were the first areas of the Great Lakes affected by human activities that altered their productivity and usefulness as a natural resource (Smith and Snell, 1891). The serious decline in abundance of the more desirable commercial species of fish in Saginaw Bay (Hile and Buettner, 1959) appears to be largely the result of man's activities.

Less is known about the bays than about the Great Lakes proper, and techniques for studying them are poorly developed. This study of Saginaw Bay provided an opportunity to test techniques previously used to evaluate the circulation of marine estuaries by applying them to the study of water exchange of a freshwater bay with the main body of the lake.

Growing concern over the decline of the more valuable fish species led to a cooperative limnological survey of Saginaw Bay by the Michigan Department of Conservation and the U.S. Bureau of Commercial Fisheries in 1956. The bay supported a prosperous recreational fishery and produced about 40% of the U.S. commercial catch of Lake Huron although it constituted only 5% of its area. The catch of lake herring *(Coregonus artedi)*, yellow perch *(Perca flavescens)*, walleye *(Stizostedion vitreum vitreum)*, and whitefish *(Coregonus clupeaformis)* in Saginaw Bay has fluctuated considerably (El-Zarka, 1959; Hile, 1954; Hile and Buettner, 1959) but clearly has declined in recent years.

Most of the early limnological studies of Saginaw Bay concerned the distribution of brine entering the bay from the oil fields and the chemical industry in the Saginaw Valley. The Dow Chemical Company, Midland, Michigan, has conducted some 30 surveys of chloride concentrations in the bay since 1933. An intensive study of the distribution of chloride was made by the Michigan Stream Control Commission from May 1, 1935, to July 2, 1936 (Michigan Stream Control Commission, 1937). Recent studies of water movements in the bay (Ayers, Anderson, Chandler, and Lauff, 1956; Beeton, 1958; Johnson, 1958) suggested that the circulation was similar to that of a marine estuary.

Data collected in the cooperative study by the Bureau and the Department, and independently by the Dow Chemical Company in 1956, are analyzed in this report to (1) extend information on physical and chemical conditions in Saginaw Bay, (2) investigate the relationship between air and water temperatures, and (3) determine the applicability in fresh water of techniques used to evaluate circulation in marine estuaries.

Morphometry

Saginaw Bay is a large identation on the west shore of Lake Huron 26 miles (42 km) wide at the mouth between Point Aux Barques and Au Sable Point, and 51 miles (82 km) long from the midpoint of a line between these points to the mouth of the Saginaw River (Fig. 1). The bay narrows to a width of 13 miles (21 km) between Point Lookout on the west shore and Sand Point on the east shore. A broad shoal at this constriction (between Charity Island and Sand Point) effectively divides the bay into outer and inner zones. The total area of 1,143 square miles (2,960 km^2) is divided about equally between the two zones, but the outer zone is considerably deeper (mean depth 48 feet [15.6 m], maximum 133 feet [40.5 m]) than the inner zone (mean depth 15 feet [4. 6 m], maximum 46 feet [14.0 m]) and contains about 70% of the total volume of the bay. The volume of water above the 18-foot (5.5 m) contour is only 32% for the outer bay, but 80% for the inner zone.

The east shore of the outer bay is rocky; the west shore has extensive sandy areas, although some rock and clay occur near Point Lookout. The shoal around Charity Island and most of the points in the outer bay are rocky. Tawas Point and Sand Point are sand spits.

The inner bay has extensive shallows. A broad sandy flat extends southward from Wildfowl Bay. Another irregular sandy flat extends from the Saginaw River along the west shore to Point au Gres. Several shallow spits off the mouths of small rivers extend over this flat perpendicular to the shore. The two large flats have extensive marshes near shore. Coryeon Reef is a sand and gravel bar between the shore southeast of the Saginaw River and the Charity Islands. Its ridge is about 6 feet (1.8 m) below the surface and it is separated over most of its length from the sandy flat near shore by water deeper than 12 feet (3.7 m).

The bay has several islands, the most prominent of which is Charity Island. A group of marshy low-lying islands (North, Stony, and Katechay) lies southwest of Sand Point. These islands are surrounded by marshy shallows from which there is no clear line of demarcation.

Collection of Data

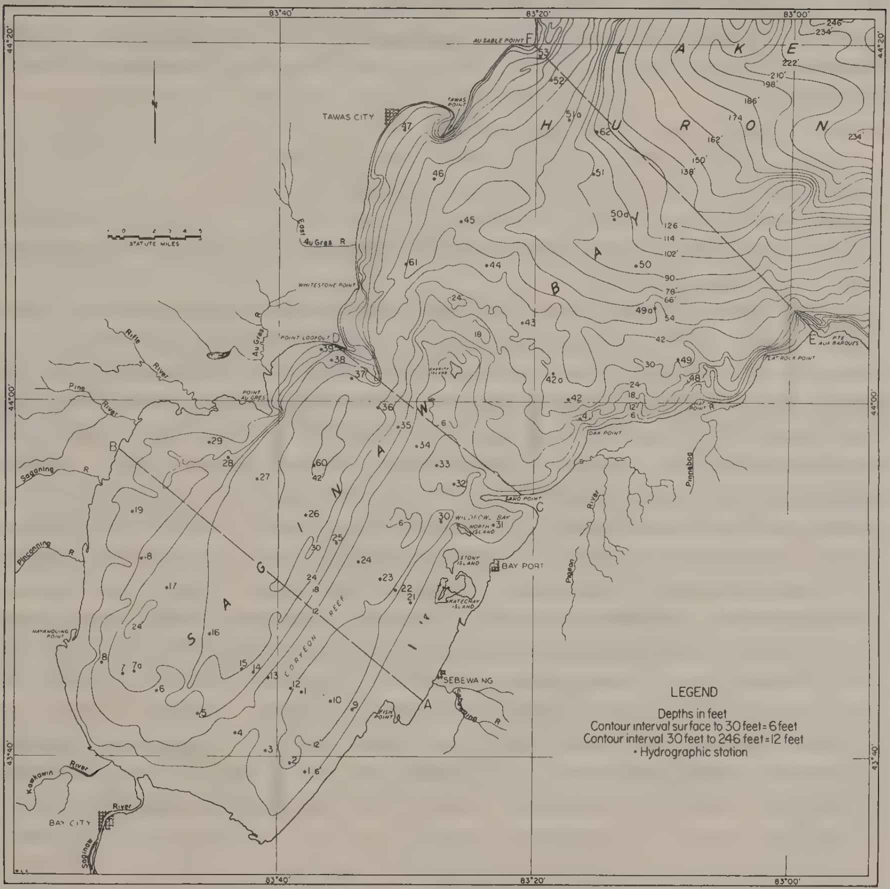
Three synoptic surveys were made by the research vessels *Cisco*, *Musky I* (Bureau of Commercial Fisheries), and the patrol boat *PB3* (Michigan Department of Conservation) on June 7, August 10, and October 30, 1956. Each vessel made two transects across the bay during each survey. The *Musky I* made the innermost transects, the *PB3* the middle transects, and the *Cisco* the outer transects. Fifty-three stations were established at selected locations along the transects and numbered consecutively, starting with number 1 in the southeast corner of the bay and ending with number 53 off Au Sable Point (Fig. 1). Station 30 was located off the transect to obtain a bottom sample where the bottom was not rocky. Stations 20 and 40 were abandoned because the water was too shallow to navigate safely. The *Cisco* made additional observations at several stations that were not originally scheduled. These stations, designated as 7a, 42a, 49a, 50a, and 51a (Fig. 1), have been included in this report.

Surface water samples were collected with a 1-pint jar and subsurface samples were obtained with either a Nansen or Kemmerer bottle. Samples were stored in 4-ounce polyethylene bottles. Surface and subsurface temperatures were measured with resistance thermometers aboard the *Musky I* and *PB3*. Surface temperatures were measured by a recording resistance thermograph and subsurface temperatures were obtained with a bathythermograph from the *Cisco*. Bottom samples were obtained at each station with a Petersen dredge, except at stations 4, 44, and 48 where the bottom was too hard to be sampled. During the first survey sediment samples were taken at each station for a study of the deposits (Wood, 1964). The distribution of the oligochaetes has been reported on by Brinkhurst (1967). Results of analysis of bottom fauna from dredge samples have not been published.

Additional observations of sky and sea state, visibility, wind direction and velocity, and cloud type were recorded by methods outlined by Beeton, Johnson, and Smith (1959). Returns from drift bottles released at a number of stations were analyzed by Johnson (1958).

The *Cisco* operated in Saginaw Bay and southern Lake Huron from June 3 to November 21, 1956, during which time collections of water, bottom fauna, plankton, fish, and thermal data were made at approximately 3-week intervals at stations 41-53, 60, and 62 in the outer zone, and at stations 60 and 7a in the inner zone (Fig. 1). Additional surface water samples and temperatures were taken and bathythermograph casts made between stations. Analyses of Secchi disc and photometer measurements of light penetration made from the *Cisco* in the bay and in Lake Huron have been completed (Beeton, 1958). Information has been published on the distribution and seasonal movements of bay fishes (Carr, 1962), and on the food of yellow perch (Tharratt, 1959) and smelt (Gordon, 1961). Thermal and chemical data collected in Lake Huron proper at stations not included in this report were presented by Allen (1964).

The dissolved oxygen was determined aboard the *Cisco* by the unmodified Winkler method. Hydrogen-ion concentrations (pH)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CHARITY ISLAND
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NORTH ISLAND
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Contour interval 30 feet to 246 feet = 12 feet
• Hydrographic station

Figure 1. Map of Saginaw Bay showing depth contours and station locations. [Lines A-B, C-D, and E-F indicate transects used for calculations of flushing rates and lakeward transport. Line C-D divides the bay into inner and outer zones, as used in this paper.]

were determined with a Hellige color comparator. All other chemical analyses were made in the Ann Arbor laboratories of the Michigan Department of Conservation and the Bureau of Commercial Fisheries

The Dow Chemical Company used one vessel for three surveys in 1956 (June 21-22, July 20-21, August 24-25). Approximately 200 measurements of specific conductance were made on each survey with a conductivity cell towed behind the vessel. Water samples were collected at 12-14 locations for analysis in their laboratory.

Laboratory Analyses

Data of the Bureau of Commercial Fisheries and Michigan Department of Conservation

Calcium, magnesium, and potassium determinations were made with a model DU Beckman spectrophotometer with flame photometer attachment. Sulfate was determined turbidimetrically after precipitation with barium (American Public Health Association, 1946) and total phosphorus was measured colorimetrically by the ammonium molybdate method (Ellis, Westfall, and Ellis, 1948). Total alkalinity was determined as methyl orange alkalinity expressed as parts per million (ppm) of calcium carbonate (American Public Health Association, 1946). Alkalinity is used as a general term in this report, since it cannot be assumed that bicarbonate, carbonate, and hydroxide are the only ions involved in the alkalinity titration. It can be assumed, however, that most of the alkalinity was due to bicarbonate ions, since the pH of the bay ranged from 7.8 to 8.4 and the presence of sufficient hydroxide ions in natural waters to affect alkalinity is considered rare (Hem, 1959). Specific conductance was measured in the laboratory with an Industrial Instruments Model RC-16b-1 conductivity bridge and is given in mhos/cm x 10^6 at 18° C ($K_{18} \times 10^6$).

Data of the Dow Chemical Company

Versenate titration was used to determine total hardness. Chloride was measured by Volhard titration. The barium turbidometric method was used for sulfate determinations.

The relation between chloride content and specific conductance of water samples analyzed in the laboratory was used to estimate chloride content from conductivity measurements made on the vessel.

Physical-Chemical Characteristics

Thermal conditions in the inner bay

Water of the inner bay had warmed considerably before the first survey on June 7. Surface temperatures ranged from 15 to 20° C (Fig. 2). The shallow littoral water along the west and east shores was warmer than the rest of the bay. A tongue of this warm water (20° C) extended out from the east shore into the open water of the lower bay. This water probably had been warmed in the extensive shallows along the east shore.

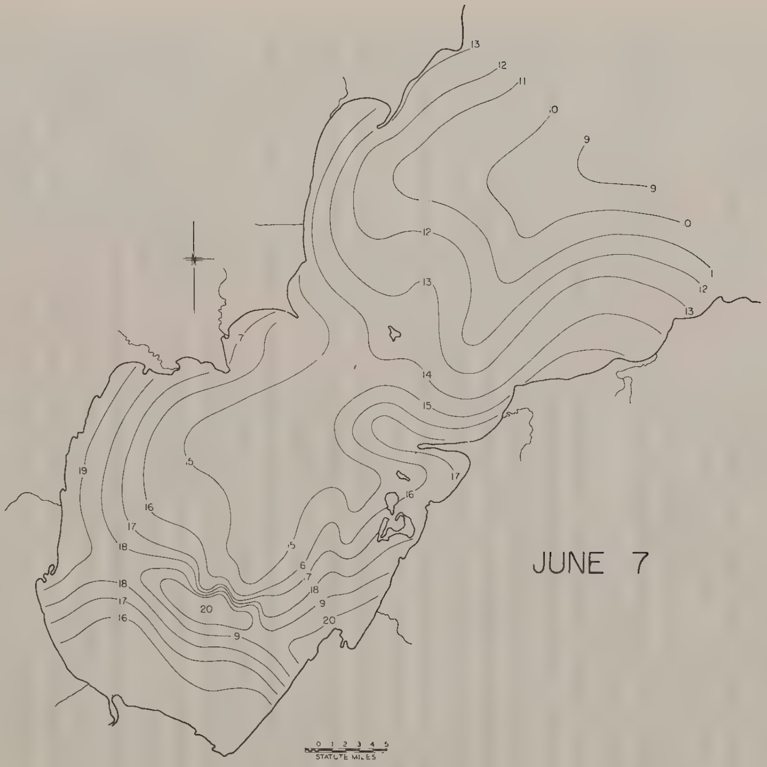
Subsurface temperatures at station 60 show that waters in the deepest part of the inner bay warmed rapidly during June (Fig. 3). By June 20 the difference was only 0.1° C between the surface and 4 meters, and 3.9° C between the surface and 9 meters (Appendix Table A-1). Warming of the deeper water continued and the inner bay was homothermous by July 22.

The water of the inner bay continued to warm into August (stations 7a and 60) and surface temperatures ranged from 22 to 24° C during the August 10 survey (Fig. 2). The warmest water was in the shallow littoral areas. The progression of warming in surface water was closely similar at stations 7a and 60 (Fig. 3), although these stations are 15 miles (24 km) apart. The surface temperatures at station 7a were 1 to 1.5° C higher than those at station 60 in June and July. This difference could be due to a faster warming of the shallow waters at station 7a or because of the penetration of cooler outer bay water into the inner bay to station 60. Differences in temperatures at these stations were minor after August 1; highest temperatures were on August 12—22.5° C at station 7a and 22° C at station 60.

The inner bay started to cool in late August and cooled rapidly during September. The rate of temperature decline decreased through October, but increased sharply in November. Except during the first week of September at station 60, homothermous conditions prevailed throughout the inner bay during most of this period of cooling. Evidently cooling progressed uniformly throughout the inner bay and by the October 30 survey temperature differences were less than 1° C (Fig. 2).

Thermal conditions in the outer bay

Surface temperatures ranged from 9 to 17° C at the time of the June 7 survey (Fig. 2). The 9 and 10° C isotherms at the mouth of the bay indicate intrusions of open-lake water. The outer bay warmed rapidly during June except for the deeper water at station 62 (Fig. 3). Temperature of the deeper waters at the bay mouth were probably influenced by Lake Huron. Station 61 appeared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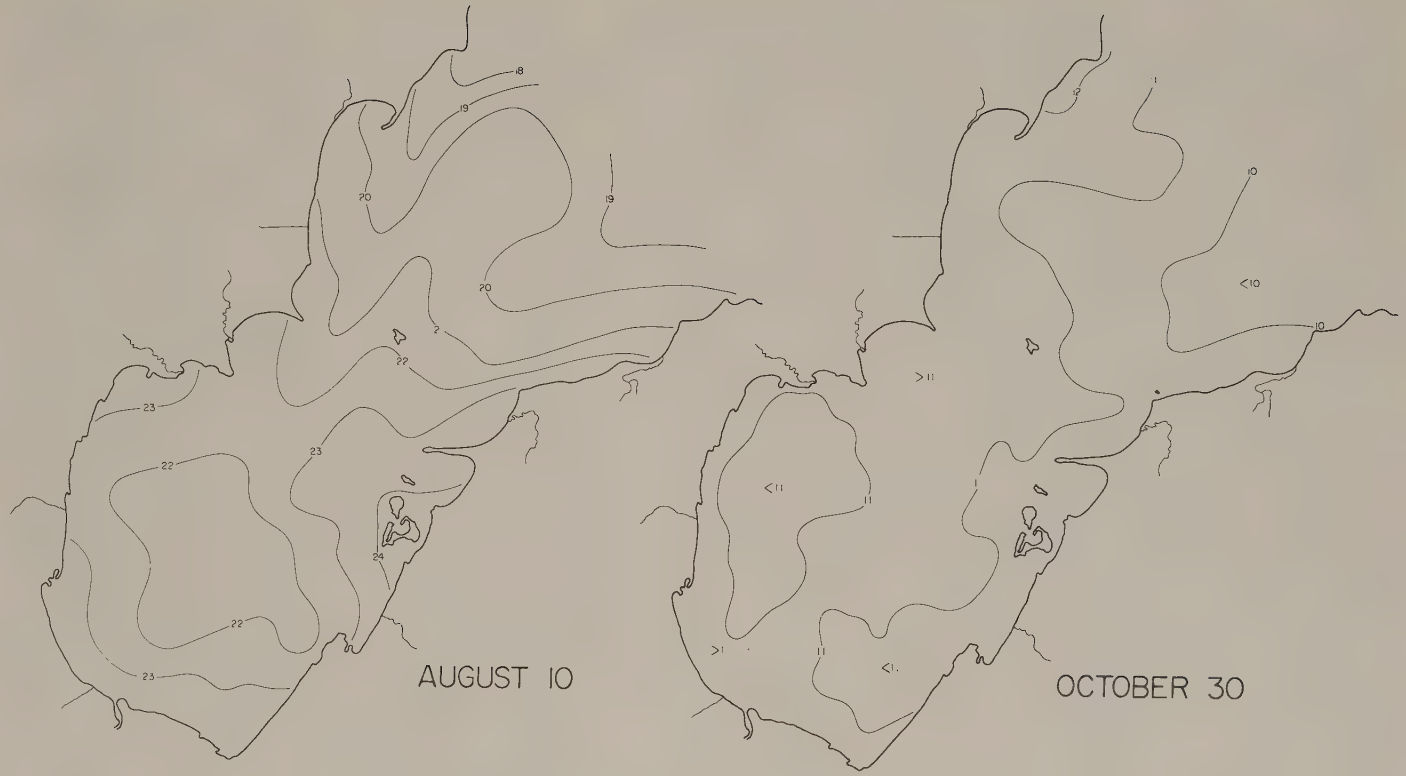
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Figure 2. Surface temperatures (oC) of Saginaw Bay during synoptic cruises on June 7, August 10, and October 30, 1956.

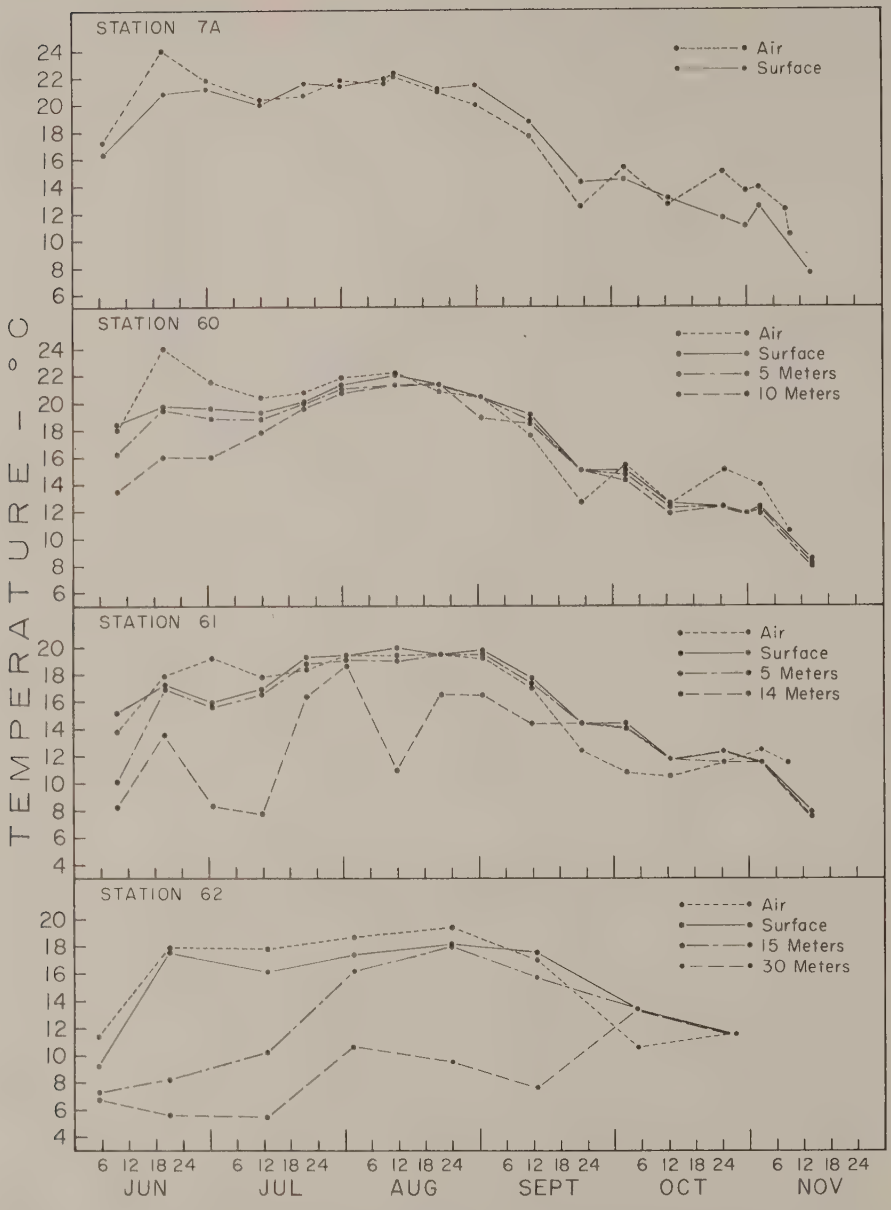


Figure 3. Air, surface, and subsurface temperatures for four locations in Saginaw Bay. Stations 7a and 60 are in the inner bay, and stations 61 and 62 in the outer bay. See Figure 1 for location of stations. [Moving averages of air temperatures for stations 7a and 60 are from Bay City, those for stations 61 and 62 are from East Tawas. Occasionally measurements were made at depths not shown—see Appendix Table A-1.]

to be in a zone where inner and outer bay waters mixed. The wide fluctuations in temperature at 14 meters at this station undoubtedly reflect intrusions of water masses from the open lake.

Warming to a depth of 5 meters progressed rapidly in the outer bay as it did in the inner bay, but surface temperatures remained about 3° C lower at station 61 and 4° C lower at station 62 than in the inner bay. Some warming at 30 meters occurred at station 62 by early August, but open-lake water at 30 meters did not warm until the 1st week of October (Allen, 1964).

Surface temperatures ranged from 18 to 23° C during the August 10 survey (Fig. 2). The warmest surface water was along the east shore and a tongue of cooler lake water penetrated the outer bay near Tawas Point.

The cooling trend that started in mid-August in the inner bay did not begin until September in the outer bay. Thermal stratification had disappeared at station 61 by August 22 and the water was homothermous throughout the fall (Fig. 3). Cooling progressed somewhat more slowly at station 62. The water was homothermous by early October and water at 30 meters attained its highest temperature (13.2° C, Appendix Table A-1) on October 5.

Surface temperatures varied little from 11° C throughout Saginaw Bay during the October 30 survey (Fig. 2). A small mass of 12° C water occurred near shore north of Tawas Point, and 10° C water occupied most of the eastern half of the outer bay.

Relation between air and water temperatures

Various attempts have been made to establish the relation between air and water temperatures because of the importance of thermal conditions to biological phenomena, and the general availability of records of air temperature where those of water temperatures are not available. Attempts to establish a relationship for day-to-day changes have not been successful. One such study was made on Saginaw Bay in 1904 (Cooper, 1905). Methods based on monthly mean temperatures have been used successfully on South Bay, Lake Huron (McCombie, 1959), and for Lake Erie (Doan, 1942).

Sufficient water temperatures were collected during this study to determine their relationship to air temperatures. The 10-day moving averages of the mean daily air temperature from Bay City showed the closest agreement with trends in water temperatures in the inner bay (Fig. 3, stations 7a and 60). Extreme fluctuations in air temperatures were not smoothed out sufficiently by 5-day moving averages to be representative of water temperatures, and 14-day moving averages did not differ appreciably from the 10-day values. Temperatures from Flint and Saginaw (not illustrated) were usually lower than the surface water temperatures in July and August, but water temperatures at stations 7a and 60 closely agreed with the 10-day moving averages of Bay City air temperatures for July and August. Air temperatures were about 1° C lower than water temperatures in September. More uniform air temperatures in October coincided with the reduced rate of cooling of the water. The greatest discrepancy between air and water temperatures occurred during the first 2 weeks of June when air temperatures increased rapidly.

Moving averages for 21 days of daily mean air temperatures from East Tawas agreed well with trends in surface water temperatures in the outer bay (Fig. 3, stations 61 and 62). The 10-day moving averages of air temperatures fluctuated too widely to be representative of the water temperature. Water temperatures to a depth of 5 meters coincided closely with air temperature from the 2nd week of July until mid-September at station 61; the discrepancies were greatest in late June and between mid-September and early October. The trend in surface water temperatures at station 62 was closely similar to that of the 21-day moving averages of air temperatures, although air and water temperatures usually differed by 1° C.

Dissolved oxygen

Dissolved oxygen was measured at five stations (Appendix Table A-1). Station 60 in the inner bay and 61 in the outer bay are used to illustrate changes in the amount of dissolved oxygen in these areas during June-November, since these stations were visited more frequently than the others.

Changes in dissolved oxygen at station 60 were apparently related to wind and temperature (Fig. 4). Dissolved oxygen content of surface water decreased 1.3 ppm during the period of substantial warming in June (Fig. 3). The greatest difference (1.8 ppm) between the surface and 10 meters occurred in the calm period when the samples were taken, on June 10 (Fig. 4). The lowest percentage of saturation (66%) occurred on June 20 at 9 meters, after this period of calm. The marked increase in dissolved oxygen on July 1 followed a period of higher wind velocities. Differences between surface and subsurface dissolved oxygen were slight over the remainder of the summer when the waters were nearly homothermous. A period of relatively calm weather in the latter part of August preceded the low dissolved oxygen concentration in the deeper water on September 1. Dissolved oxygen increased slightly at all depths as the water cooled and winds became stronger in September, October, and November. Despite this increase, the percentage saturation decreased in the fall as temperature declined.

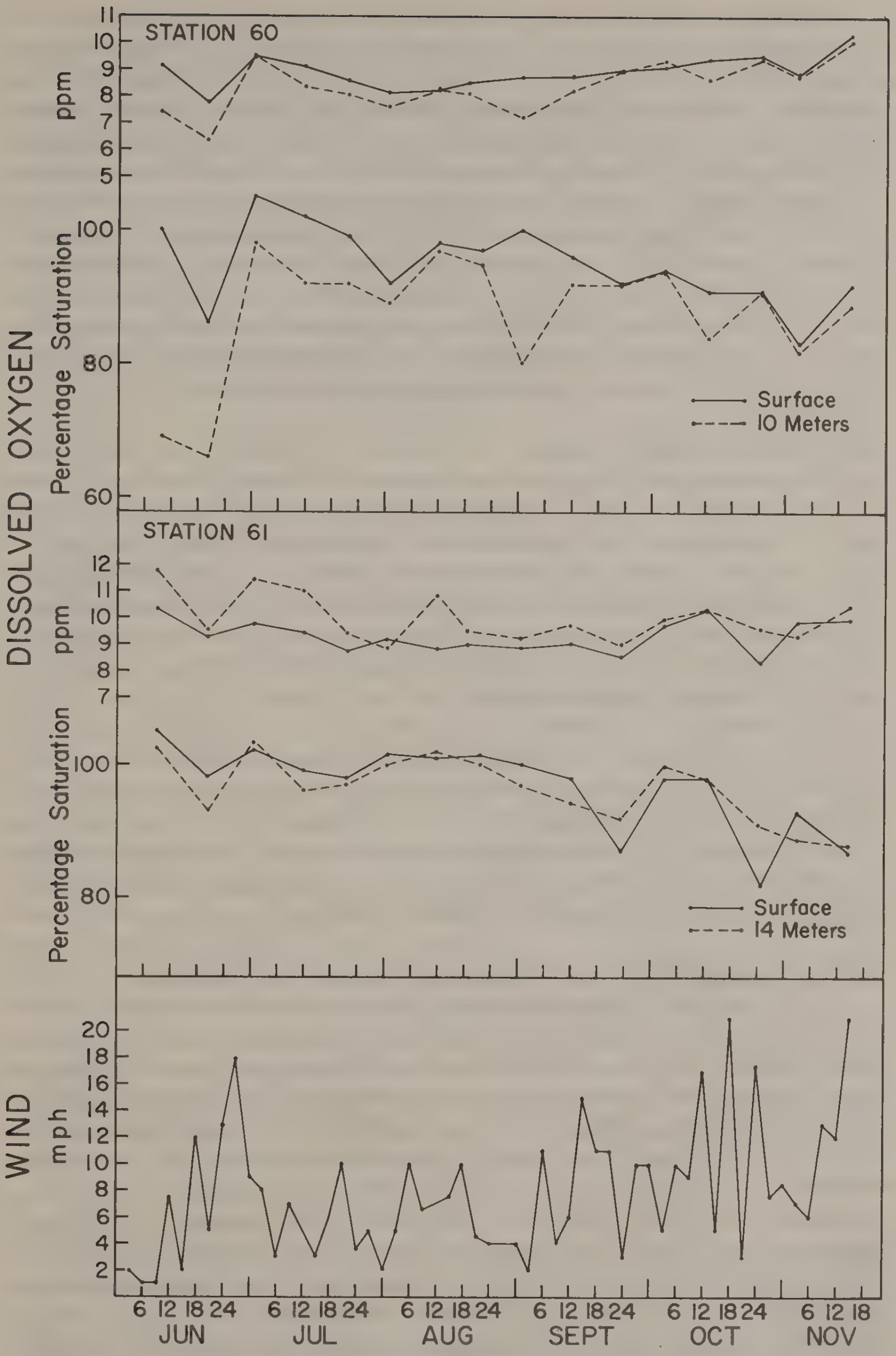


Figure 4. Dissolved oxygen concentrations at two stations in Saginaw Bay and average daily wind velocity for 3-day intervals at East Tawas, 1956.

Changes in dissolved oxygen at the surface in the outer bay at station 61 were similar to those described for station 60, although concentrations were usually 1 ppm greater (Fig. 4). The dissolved oxygen in the bottom water (14 meters) was usually greater than at the surface and greater than in the bottom water at station 60. This situation undoubtedly resulted from invasion of colder bottom water that originated farther out in the bay or from the lake proper, since the dissolved oxygen values and temperatures frequently corresponded to those observed at stations 62 (Appendix Table A-1) or 63 (Allen 1964, 28 miles [45 km] east of station 62) at comparable depths. Intrusions of lake water into this area also would contribute to the fluctuations in temperature (Fig. 3) and dissolved oxygen concentrations (Fig.4).

Hydrogen-ion concentration

Changes in pH of the surface waters followed the same trend in all areas of the bay. The pH increased from 7.9-8.1 in early June to a high of 8.4 in July, then decreased more gradually to lower values in late October and early November (Appendix Table A-1). A similar increase in July and decrease in October and November occurred in the bottom waters at the shallow stations 42, 45, 60, and 61, but the pH showed no trends in the deeper water at station 62 during June-October.

Fluctuations of pH were pronounced at station 62 at the mouth of the bay. The pH of surface water increased to 8.3 in July, dropped to 7.9 in early August, and increased again to 8.2 in late August. The pH of bottom water ranged from 7.6 to 8.0. Changes at this station probably reflected movement of Lake Huron water into and out of the area, since the lower pH values were similar to those of Lake Huron water (Allen, 1964).

Distribution of major constituents of Saginaw Bay and River

The chemical characteristics of Saginaw River water varied considerably due to high but varying concentrations of salts in brine waste discharged to the river (Michigan Stream Control Commission, 1937). Dow Chemical Company's analyses of Saginaw River water during May, June, and July, 1956, show that concentrations of chloride (as NaCl) ranged from 64 to 614 ppm, total alkalinity (as $CaCO_3$) from 123 to 187 ppm, sulfate from 70 to 115 ppm, and total hardness (as $CaCO_3$) from 168 to 434 ppm. These values followed no seasonal trend since discharge of waste brine into the river from storage ponds for chemical wastes was irregular. For example, the chloride content of river water was: 614 ppm on June 13, 1956; 421 ppm on June 20; 199 ppm on June 27; 374 ppm on July 11; 608 ppm on July 18; and 404 on July 25.

Changes in concentrations of the major ions with depth in the bay were much less than differences in surface concentration at various locations (Appendix Tables A-2, A-3, and A-4). Differences in ion content between surface and subsurface waters were ordinarily 1 ppm or less and were within the range of the reliability of the methods of analysis. Concentrations of some ions were higher at the surface than near the bottom, and others were lower at the surface. It appears, however, that in the outer bay the ion content was slightly lower near the bottom than near the surface.

Of the cations in the inner bay water, calcium was highest, magnesium ranked second, sodium third, and potassium fourth (Table 1). Total cation concentrations were very high in June (4.44 epm), were somewhat less in August, and decreased to 3.27 epm in October. Changes in the total cation concentrations were primarily due to changes in amounts of calcium. These values were much greater than for the average freshwater of the world (Table 1).

Concentrations of all ions were considerably lower in the outer bay (Table 2), where they were not much higher than in Lake Huron proper (Allen, 1964). The proportions of the various cations and anions were similar to the average proportions for freshwaters of the world, except for chloride (Gorham, 1957). Chloride, although not high, differed from the world average in that it exceeded sulfate.

The dilution of Saginaw River water as it moved through the bay is shown by a decrease of average concentrations of the major ions and specific conductance from the inner bay to the outer bay (Tables 1 and 2). Near the river mouth the specific conductance was 800 μmhos and the total cation concentration was 6.03 epm on June 7, when conductivity was 206 μmhos and cation concentration was 2.01 epm at the mouth of the bay. The small change in the ratio between total cations and specific conductance throughout the bay illustrates the uniform dilution of river water (Fig. 5). The dilution of the Saginaw River water from the river mouth to the bay mouth must have been due to inflow from Lake Huron, since the discharge from other tributaries was minor (Appendix Table A-5). Lake Huron water had an average conductivity of 174 μmhos and an average cation content of 1.98 epm.

Distribution of chemical constituents

Closest agreement in the distribution of various chemicals measured during the synoptic surveys was among sodium, calcium, sulfate, and conductivity, and least agreement was between these and distributions of potassium, magnesium, phosphorus, and total alkalinity. Some of the differences in distributions may reflect

Table 1. Average chemical characteristics of water samples taken in the inner area (inside line A-B, Fig. 1), of Saginaw Bay in 1956

Date	Cations					Anions				Specific conductance (µmhos 18°C)
	Calcium (ppm)	Magnesium (ppm)	Potassium (ppm)	Sodium (ppm)	Total cations (epm)	Bicarbonate[1] (ppm)	Chloride (ppm)	Phosphorus (ppm)	Sulfate (ppm)	
June 7	55	11.2	3.6	15.8	4.44	155	-	0.045	29	553
June 22	-	-	-	-	-	-	57.5	-	-	-
Aug. 10	45	10.6	3.0	16.2	3.90	139	-	0.037	22	463
Aug. 25	-	-	-	-	-	-	61.4	-	-	-
Oct. 30	39	9.4	2.0	11.6	3.27	135	-	0.042	16	391
Average	46	10.4	2.9	14.5	3.87	143	59.5	0.041	22	469
Average expressed as epm	2.31	0.86	0.07	0.63	3.87	2.34	1.68	-	0.46	-
World average freshwater as epm[2]	1.49	0.42	0.08	0.36	2.35	1.71	0.23	-	0.37	-

[1] Determined from total alkalinity measurements.
[2] Gorham, 1957.

Table 2. Average chemical characteristics of water samples taken in the outer area (between lines A-B and E-F, Fig. 1), of Saginaw Bay in 1956

Date	Cations					Anions				Specific conductance (µmhos 18°C)
	Calcium (ppm)	Magnesium (ppm)	Potassium (ppm)	Sodium (ppm)	Total cations (epm)	Bicarbonate[1] (ppm)	Chloride (ppm)	Phosphorus (ppm)	Sulfate (ppm)	
June 7	31	8.1	1.5	4.3	2.44	117	-	0.013	12	270
June 22	-	-	-	-	-	-	13.6	-	-	-
Aug. 10	29	7.5	1.2	3.6	2.25	123	-	0.024	12	253
Aug. 25	-	-	-	-	-	-	8.4	-	-	-
Oct. 30	27	7.9	1.0	2.9	2.15	113	-	0.016	10	237
Average	29	7.8	1.2	3.6	2.28	118	11.0	0.018	11	253
Average expressed as epm	1.45	0.64	0.03	0.16	2.28	1.93	0.31	-	0.23	-
World average freshwater as epm[2]	1.49	0.42	0.08	0.36	2.35	1.71	0.23	-	0.37	-

[1] Determined from total alkalinity measurements.
[2] Gorham, 1957.

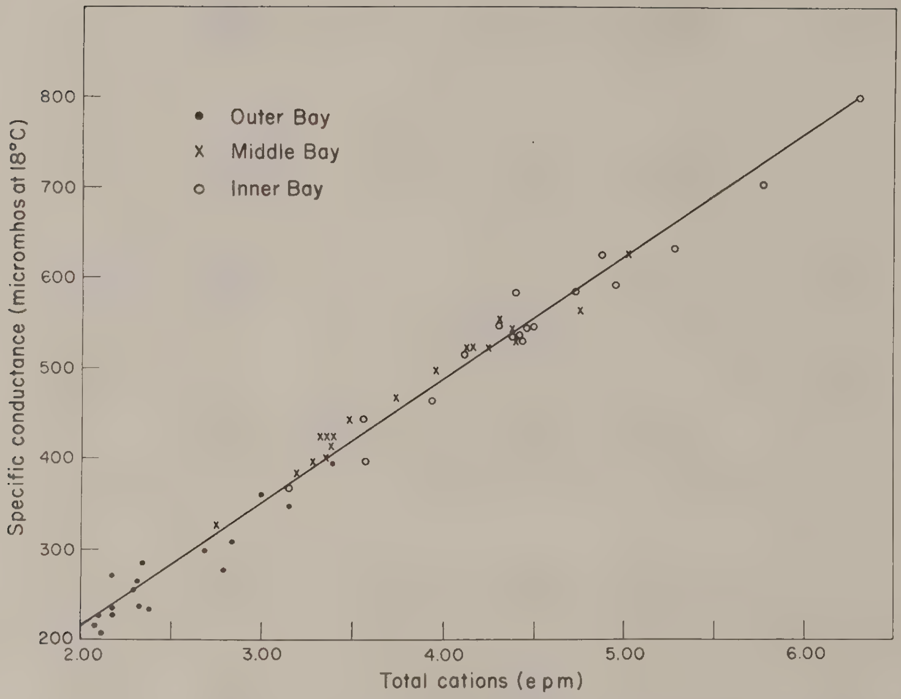


Figure 5. Relationship between specific conductance and total cation concentrations in three areas of Saginaw Bay, June 7, 1956.

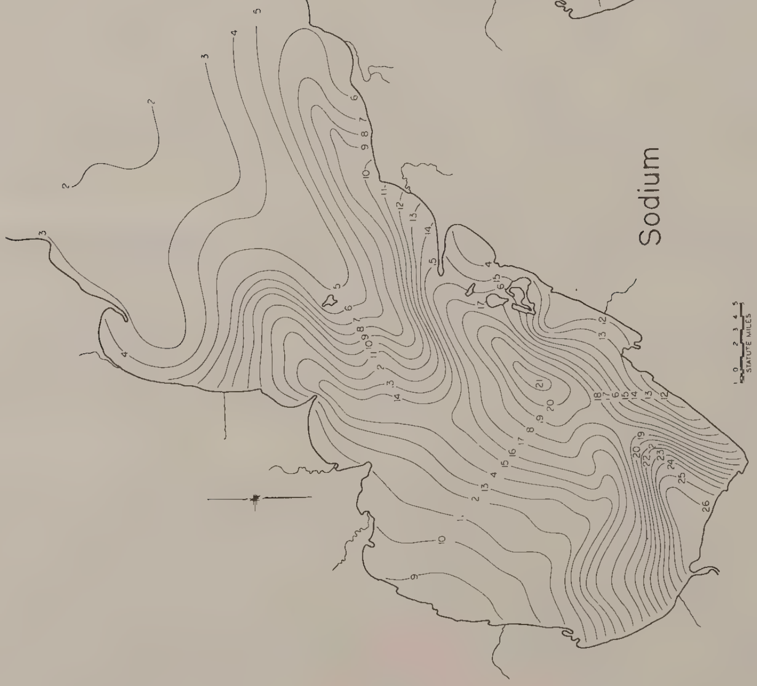
the accuracy of chemical analyses or subjective contouring. Consequently, emphasis has been placed on major patterns in the distributions and not on minor details.

Synoptic survey I, June 7.— Water with a high sodium content extended along Coryeon Reef from the Saginaw River mouth (26 ppm) to the vicinity of Sand Point (15 ppm, Fig. 6). Part of this water mass extended well beyond Sand Point to Flat Rock Point, but dilution was considerable in the outer bay and the sodium content had decreased to 6 ppm at Flat Rock Point. Some of the water with high sodium content extended north to Point Lookout and into the outer bay. Water low in sodium occupied much of the outer bay and extended into the inner bay near Charity Island. Sodium concentrations were relatively low in the inner bay along the northwest shore (9 ppm) and the southeast shore (12 ppm). This condition may have resulted from isolation of Lake Huron water that entered the bay earlier, or from dilution by the inflow from tributaries or surface runoff. The survey was made shortly after the period of maximum discharge from tributaries that have a lower sodium content than the inner bay (Appendix Table A-5).

The distributions of calcium, sulfate, conductivity, potassium, and magnesium were similar to that of sodium (Figs. 6 and 7). Values for all were relatively low along the northwest and southeast shore of the inner bay. The low concentrations of calcium and sulfate in the northwest area strengthen the assumption that these areas of dilution resulted from entrapment of Lake Huron water. Although the Rifle River, which flows into the northwest area, is low in calcium, its sulfate content is high (Appendix Table A-5). The dilutions in these areas reflect more closely the characteristics of lake water.

The distribution of alkalinity (Fig. 7) agreed generally with that of sodium. The highest alkalinity values were in areas affected by Saginaw River outflow and extended toward Sand Point. A pronounced deflection of this high alkalinity water toward the north shore was a major feature of the distribution. The mass of water of low alkalinity extending into the inner bay near Charity Island, appeared to penetrate farther toward the southeast shore than shown by other measures.

The distribution of phosphorus showed the least agreement with the distribution of sodium, except for high concentrations in areas influenced by Saginaw River outflow (Fig. 7). Phosphorus concentrations in this area were 70 parts per billion (ppb), but two-thirds of the bay had concentrations of 20 ppb or less. The decrease in phosphorus content of the water between the Saginaw River mouth and Sand Point (72%) was greater than for other measures. All of the other ions and conductivity decreased 35 to 40%.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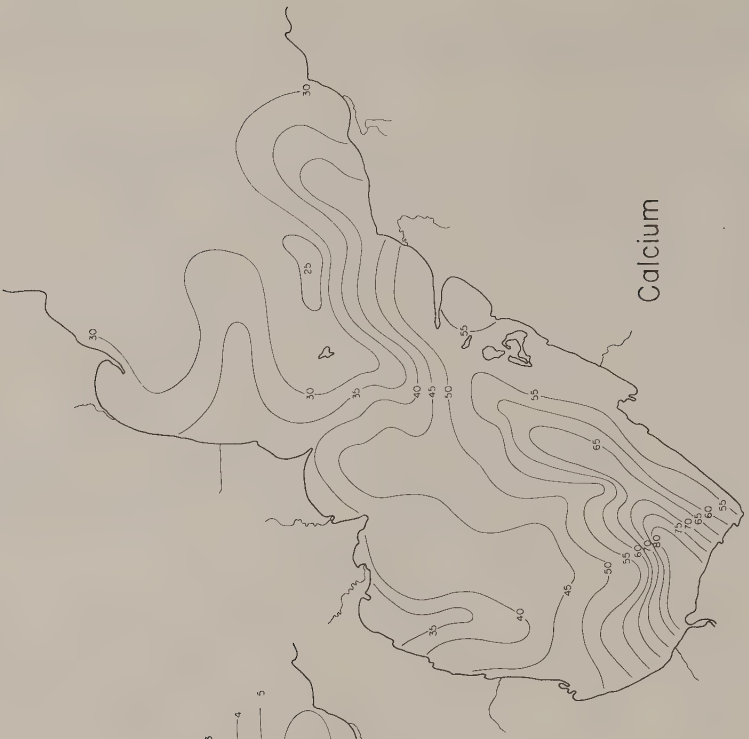
STATUTE MILES

Sodium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35
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45
50
55
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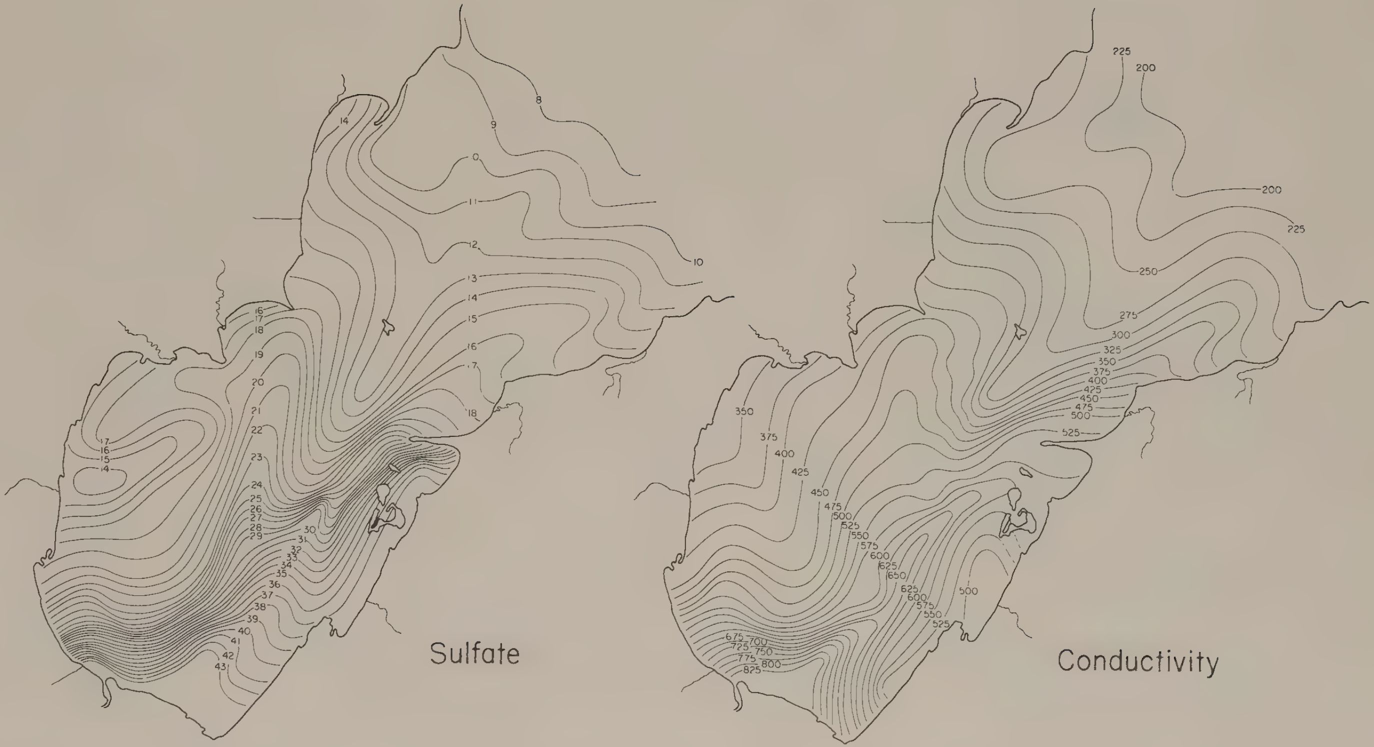
65
70
75
80

Calcium


Sulfate
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9
10
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12
13
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16
17
18
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21
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24
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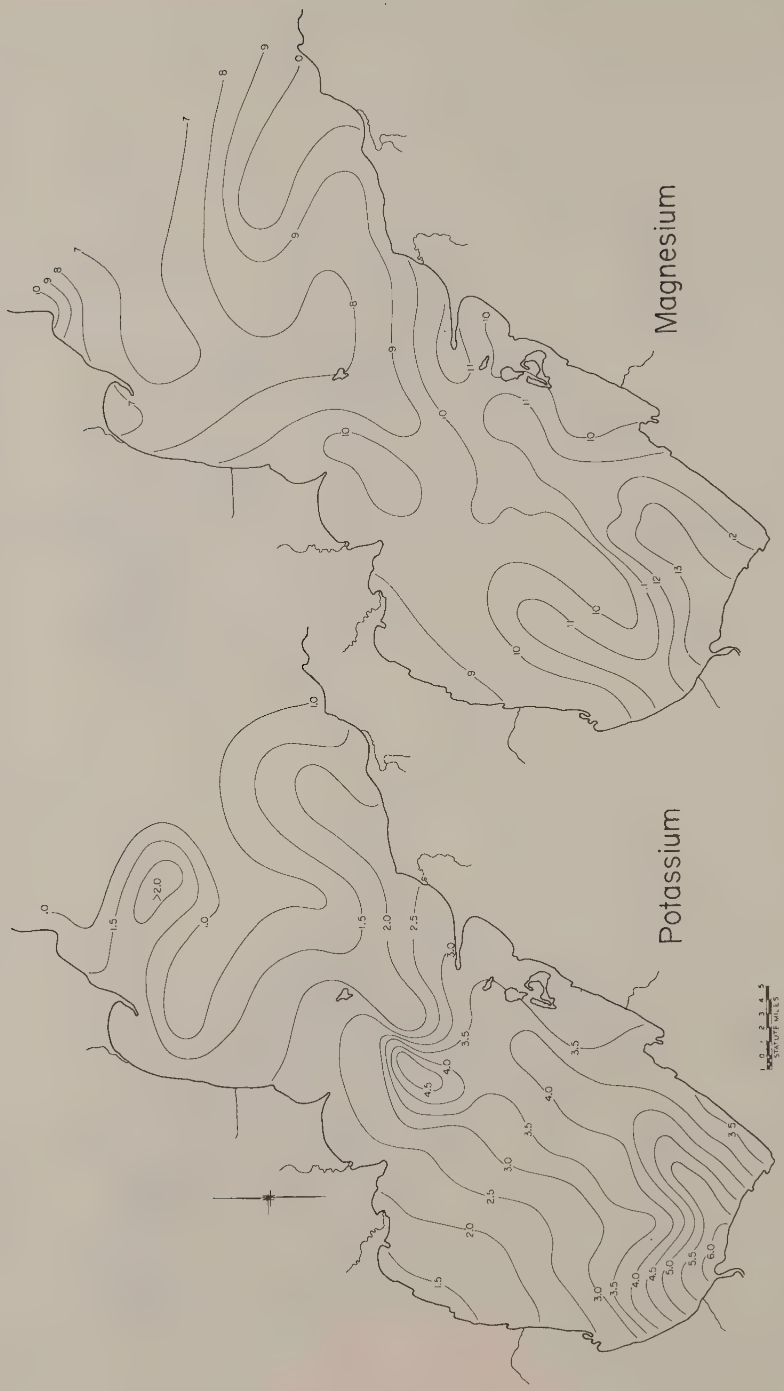
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
Conductivity
200
225
250
275
300
325
350
375
400
425
450
475
500
525
550
575
600
625
650
675
700
725
750
775
800
825

Figure 6. Distribution of sodium, calcium and sulfate (ppm), and conductivity (μmhos at 18 °C) in Saginaw Bay, June 7, 1956.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8
9
10
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12
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Potassium
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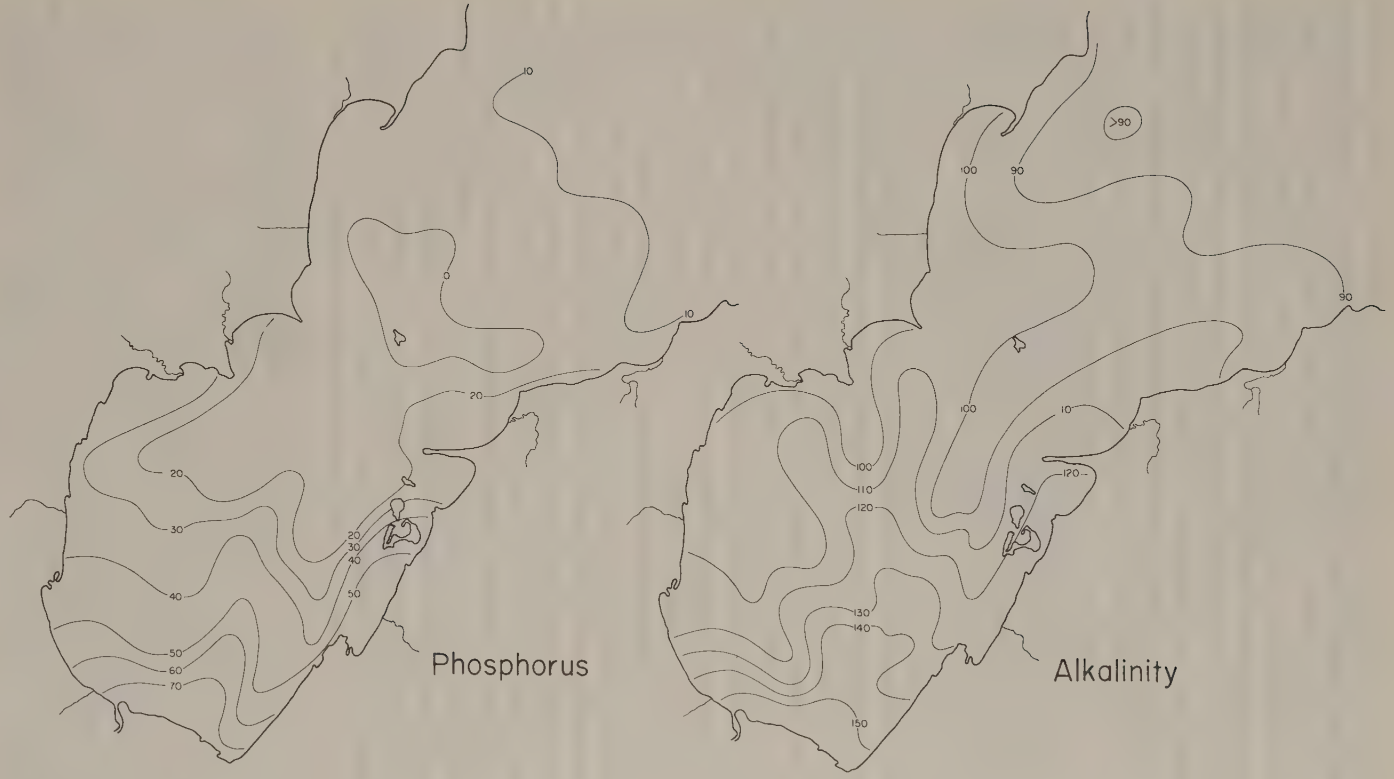
5.5
6.0
0 1 2 3 4 5
STATUTE MILES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0
10
20
20
30
20
30
40
40
50
50
60
70
Alkalinity
>90
100
90
90
100
10
100
110
120
120
130
140
150

Figure 7. Distribution of potassium and magnesium (ppm), phosphorus (ppb), and alkalinity (ppm $CaCO_3$) in Saginaw Bay, June 7, 1956.

The distribution of the various constituents suggests a deflection of the Saginaw River outflow to the southeast as it entered the bay, and a flow of river water along the Coryeon Reef. The predominant circulation was probably counterclockwise in the inner bay and some of the diluted river water was deflected toward Point Lookout where it was influenced by a general counterclockwise circulation in the outer bay. The main outflow of river water from the inner bay was probably around Sand Point where it was diluted as it mixed with outer bay water. Lake Huron water was dominant in the outer bay and was obviously flowing into the bay in the northern half of its mouth. The outflow from the bay through the southern half of the mouth would have consisted of a mixture of lake and bay water. These proposed currents agree closely with current trajectories based on returns from drift bottles released on June 7 and 10, 1956 (Johnson, 1958).

Distribution of chloride June 21-22.—The distribution of chloride during the survey by Dow Chemical Company on June 21-22 (Fig. 8) was similar in several aspects to the distribution of other constituents on June 7 (Fig. 6 and 7). The high chloride concentration near shore in the southeast corner of the bay suggests a southeast deflection of Saginaw River water similar to that on June 7. A partly isolated mass of water high in chloride northeast of the river mouth indicated, however, that the river water must have been deflected northwestward sometime between June 7 and June 21-22. A diluted mass of water high in chloride extended northward across the inner bay and into the outer bay, and low chloride water extended southeasterly from the northwest shore into the inner bay. The difference in distribution of chloride on June 21-22 from the other ions on June 7 indicates a greater influx of lake water into the inner bay had occurred, since dilution gradients were not great, except near the Saginaw River mouth. In the outer bay the greatest difference from the June 7 survey was the northerly extension (almost to Tawas Point) of water of high concentration from the inner bay; concentrations were higher in the northern half of the bay mouth than in the southern half.

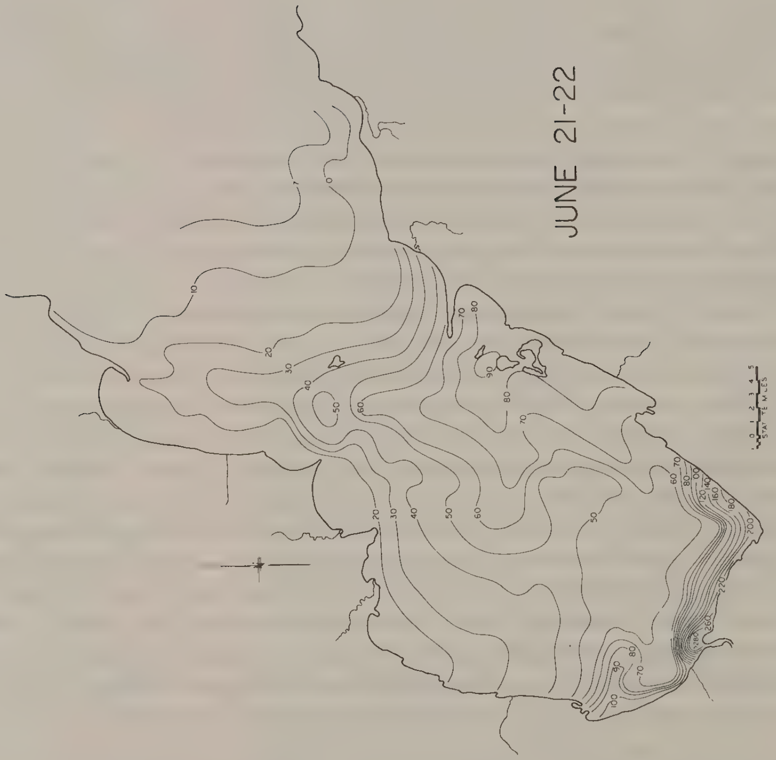
The distribution of chloride on June 21-22 indicates that circulation had changed since the June 7 survey. Circulation in the inner bay may have shifted from counterclockwise on June 7 to clockwise and back to counterclockwise in response to winds that were from the southwest shortly after June 7 but shifted abruptly to the northeast during June 15-18 (Johnson, 1958). The protrusion of inner bay water between Point Lookout and Charity Island into the outer bay and the occurrence of water with a low chloride content in the southern part of the bay mouth suggest a clockwise circulation in the outer bay. Lake Huron water was probably entering the mouth of the bay along the southern shore and inner bay water was probably flowing into the lake along the northwest shore of the outer bay.

Recoveries of drift bottles released on June 20 and 21 offer additional evidence for a clockwise circulation in the outer bay (Johnson, 1958). Most of the bottles released 5 miles (8 km) southwest of Tawas Point moved northeasterly and were recovered along Tawas Point; recoveries of bottles released elsewhere also suggest a clockwise circulation.

Distribution of chloride July 20-21.--High chloride concentration on July 20-21 extended from the mouth of the Saginaw River along the southeast shore of the bay to Sand Point as on June 21-22, but the high chloride water from the inner bay protruded into the outer bay around Charity Island instead of between Point Lookout and the island (Fig. 8). An isolated mass of water with high chloride content north of the river was similar to that of June 21-22. The low chloride water from the lake entered the bay between Point Lookout and Charity Island and extended almost 20 miles (32 km) southward into the southern corner of the bay. Chloride concentrations were not low enough to draw the 7 ppm isopleth in the outer bay. Water with the lowest chloride content occurred along the north and south shores of the outer bay.

The high chloride water along the west shore as well as the southeast shore of the inner bay and the isolated area of high chloride northwest of the Saginaw River provide additional evidence of frequently shifting circulation in the bay. The direction of circulation in the inner bay must have changed at least twice since the June 21-22 survey. The intrusion of low chloride water into the inner bay between Point Lookout and Charity Island suggests a counterclockwise circulation in the outer bay that brought Lake Huron water into the bay shortly before the July 20-21 survey. Recoveries of drift bottles released on July 12, indicated a counterclockwise circulation in the outer bay (Johnson, 1958); winds were predominantly from the southwest during July 7-14.

Synoptic survey II, August 10.— Water of high sodium content extended from the Saginaw River mouth along both the southeast and northwest shores of the inner bay on August 10 (Fig. 9). The distribution of this water along the southeast shore was similar to that in June (Fig. 6), although the sodium content was less and the water mass did not extend as far beyond Sand Point. The presence of a large mass of high sodium water to the north of the river mouth on August 10 was a major difference between the distribution of sodium in June and August. This water mass occupied much of the area where the sodium content was low along the



JUNE 21-22

10
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30
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70
80
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120
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160
180
200
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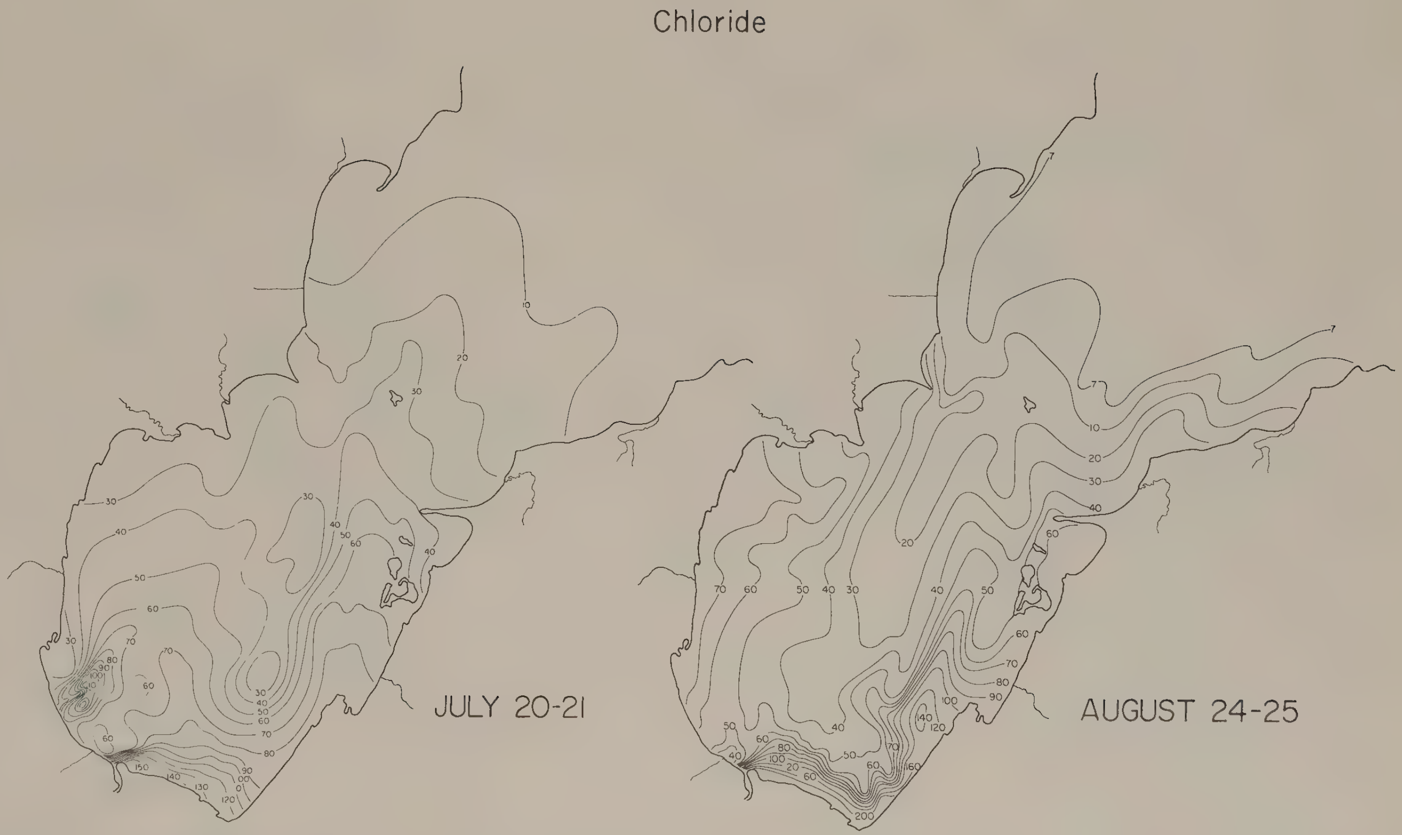
260
280
0 1 2 3 4 5
STATUTE MILES

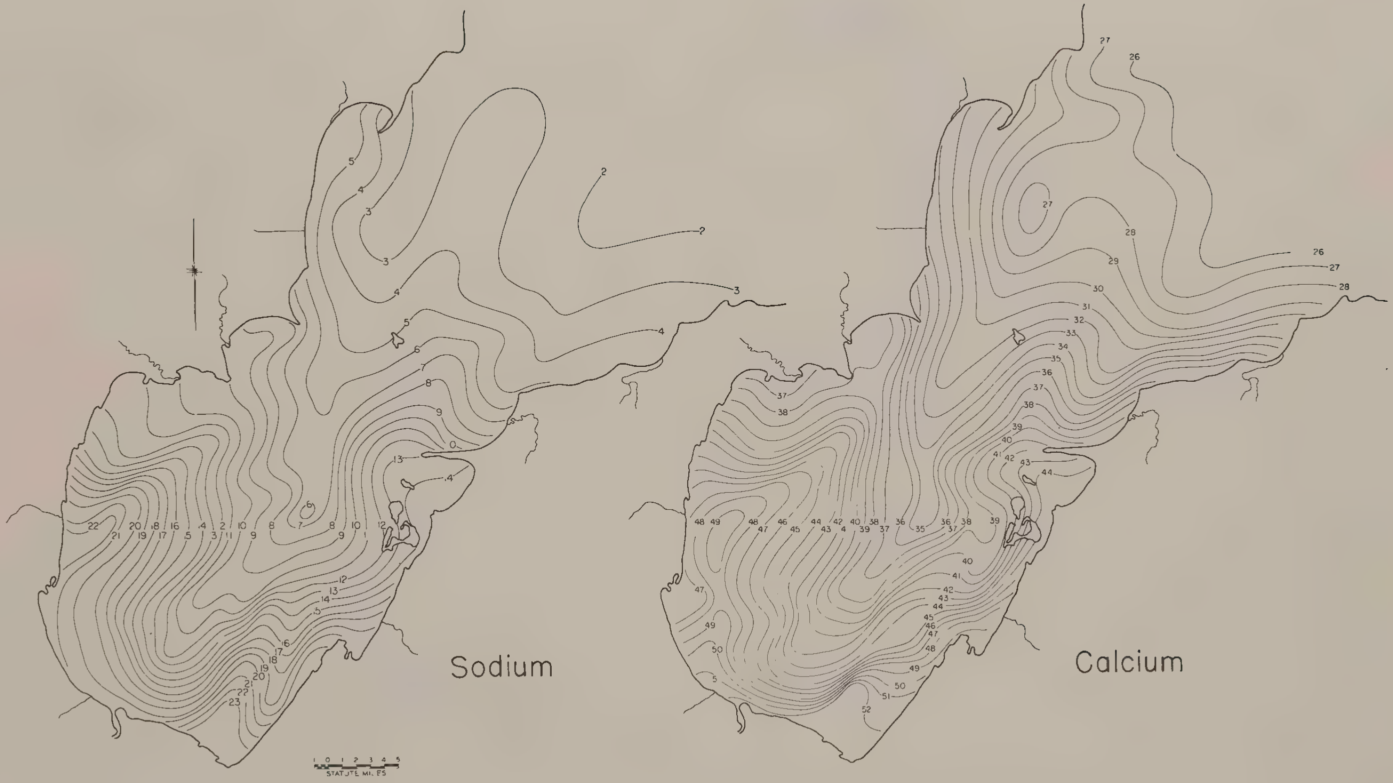


Chloride
10
20
30
40
50
60
70
80
90
100
120
130
140
150
160
200

JULY 20-21

AUGUST 24-25

Figure 8. Distribution of chloride (ppm) June 21-22, July 20-21, and August 24-25.


Sodium
Calcium
1 0 1 2 3 4 5
STATUTE MILES

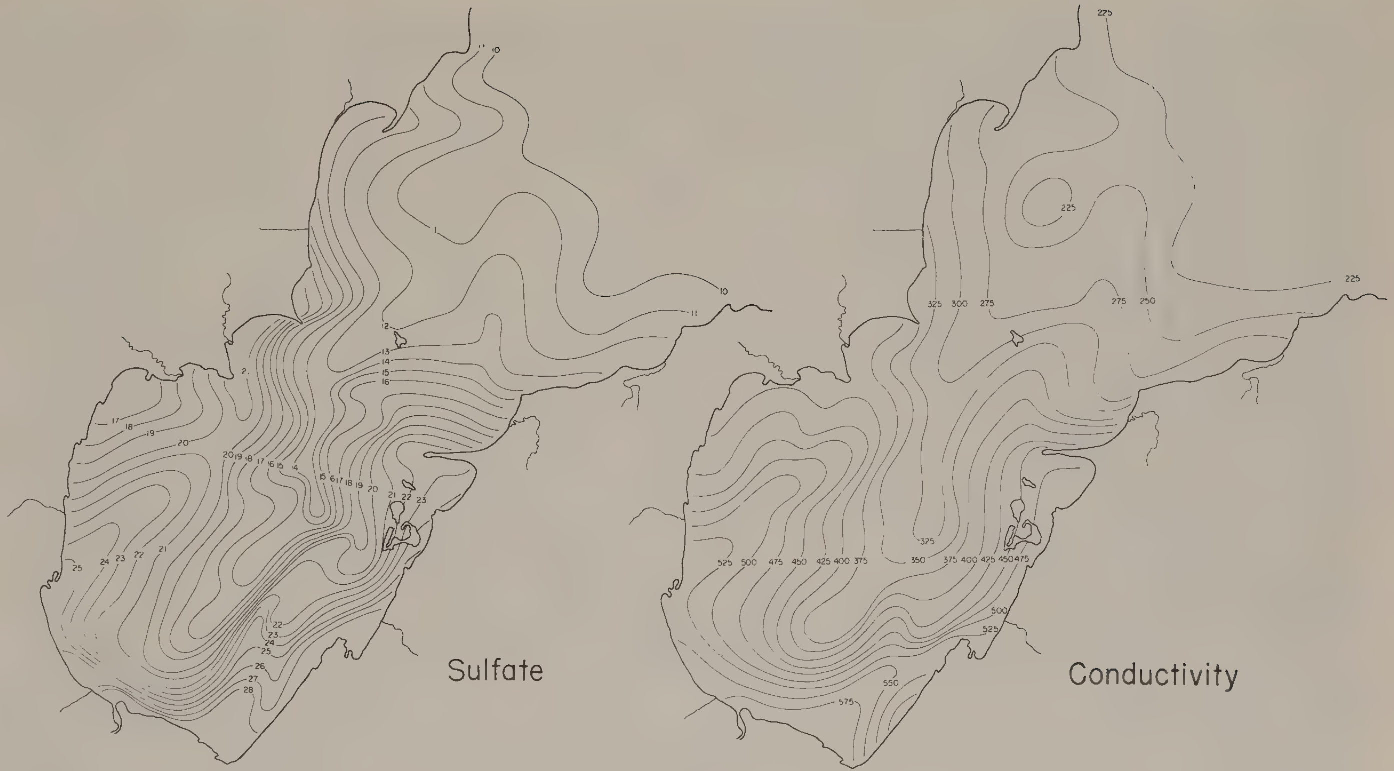

Sulfate
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
Conductivity
225
250
275
300
325
350
375
400
425
450
475
500
525
550
575

Figure 9. Distribution of sodium, calcium and sulfate (ppm), and conductivity (μmhos at 18°C) in Saginaw Bay, August 10, 1956.

northwest shore in June. Low sodium water which extended into the inner bay east of Charity Island in June was west of the island in August and had penetrated much farther into the inner bay; the 7 ppm isopleth extended about 12 miles (19.3 km) farther into the inner bay. Only one small area of the outer bay, between Sand Point and Charity Island, had sodium concentrations greater than 5 ppm. Sodium concentrations were lower on August 10 than on June 7 throughout the outer bay. Concentrations of sodium were lowest in the southern half of the bay mouth.

Distributions of calcium, sulfate, and conductivity were similar to that of sodium (Fig. 9). Slight differences in the distribution of sodium compared to calcium and sulfate appeared in the vicinity of the Au Gres and Rifle Rivers. The slightly lower calcium content near the mouth of the Rifle River may represent dilution by river water of a lower calcium content. Sulfate concentrations were slightly higher near the mouth of the Au Gres River which has a higher sulfate content than adjacent streams (Appendix Table A-5). Sulfate content of bay water west of the Rifle River mouth was lower than in any of the rivers analyzed. Other rivers entering the bay have such low discharges, especially during August, that they probably have little influence on the ion content of bay water.

The distribution of alkalinity, magnesium, phosphorus, and potassium (Fig. 10) agreed less well with sodium. Highest concentrations were north and east of the Saginaw River mouth. The higher magnesium values of the inner bay and the low magnesium concentrations at the bay mouth corresponded with sodium. Other features of the magnesium distribution were not like those of sodium. Penetration of low magnesium water into the bay was not clearly indicated as with sodium. Alkalinity was high at the mouth of the Saginaw River and in the southern corner of the bay, but high values did not extend to the north and northeast as did those of sodium. Water of low alkalinity occurred throughout the outer bay and a tongue of low alkalinity water penetrated the inner bay west of Charity Island; but unlike sodium, this intrusion extended southward to Katechay and Stony Islands.

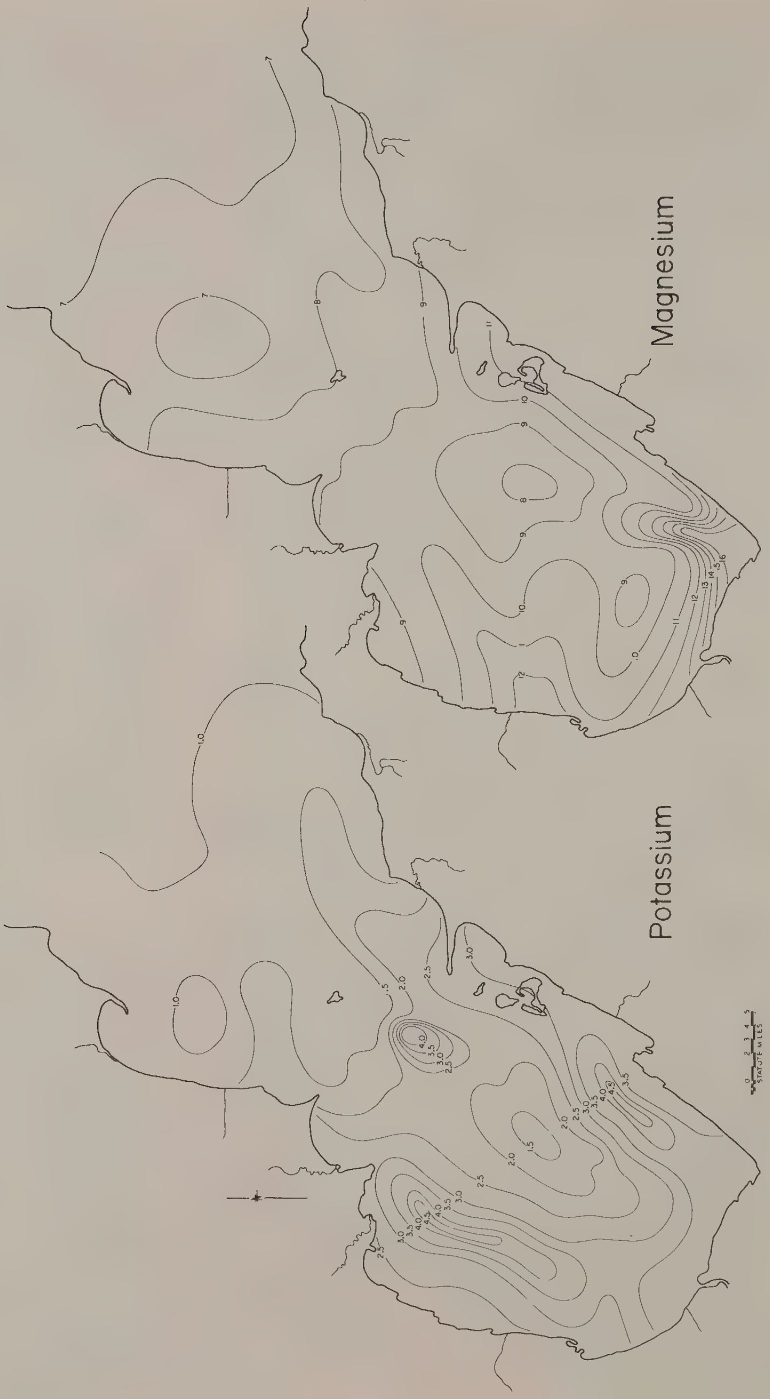
Concentrations of phosphorus were high on both sides of the river mouth and along the southeast shore to Sand Point; phosphorus content was low in the outer bay. Low phosphorus water extended through the middle of the outer bay and into the center of the inner bay instead of penetrating the inner bay west of Charity Island as for most ions including sodium. Water along both shores of the outer bay had high phosphorus concentrations. The highest concentration (70 ppb) was in Tawas Bay near Tawas City. An isolated mass of water high in phosphorus appeared off Point Au Gres.

Distribution of potassium differed most from that of other ions. Highest concentrations were at three isolated locations within the inner bay: near the southeast shore, near the northwest shore, and near the middle of the bay between Sand Point and Point Lookout (Fig. 10). Except for a small area near Sand Point influenced by outflow from the inner bay, potassium concentrations in the outer bay did not exceed 1.5 ppm.

The two masses of water of high ion content along the north and southeast shore on both sides of the Saginaw River mouth suggest that the August 10 survey was made during a period when the current pattern of the bay was changing. A counterclockwise circulation of the inner and outer zones, similar to the one described for the June 7 survey, appears to have been developing after a period of clockwise circulation. The earlier clockwise movement is indicated by the high ion content of the water north of the river mouth and by the low ion content of the water in the south half of the bay mouth. Clockwise movement within the inner bay seems to have moved river water along the northwest shore and around Point Lookout into the outer bay. Winds from the northeast, east, and southeast from July 15 to August 6 would have created such a circulation. The higher ion concentrations and higher conductivity of water in the southern corner and along the southeast shore, as well as the penetration of low ion water into the inner bay on the west side of Charity Island, suggest a more recent counterclockwise circulation. This movement was probably established between August 6 and 10 by winds from the southwest and west. This current pattern agrees with the trajectories plotted from returns of drift bottles (Johnson, 1958).

Distribution of chloride August 24-25.—Water of high chloride content extended from the mouth of the Saginaw River to the southeastern corner of the bay and northeastward toward Sand Point along the south side of Coryeon Reef (Fig. 8). Chloride content was high around Sand Point and along the southeast shore of the outer bay. An isolated mass of water of high chloride content occurred along the west shore of the inner bay. Low chloride concentrations (40-50 ppm) near the mouth of the Kawkawlin River may represent the outflow of this river (Appendix Table A-4). Most of the outer bay had low chloride concentrations—7 ppm or less. A tongue of low chloride water extended almost 20 miles (32 km) into the inner bay between Point Lookout and Charity Island.

The deflection of Saginaw River water to the right as it entered the bay, the presence of water of high chloride content along the southeast shore, and the penetration of outer bay water into the inner bay between Point Lookout and Charity Island indicate a counterclockwise circulation. Lake Huron water apparently was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16
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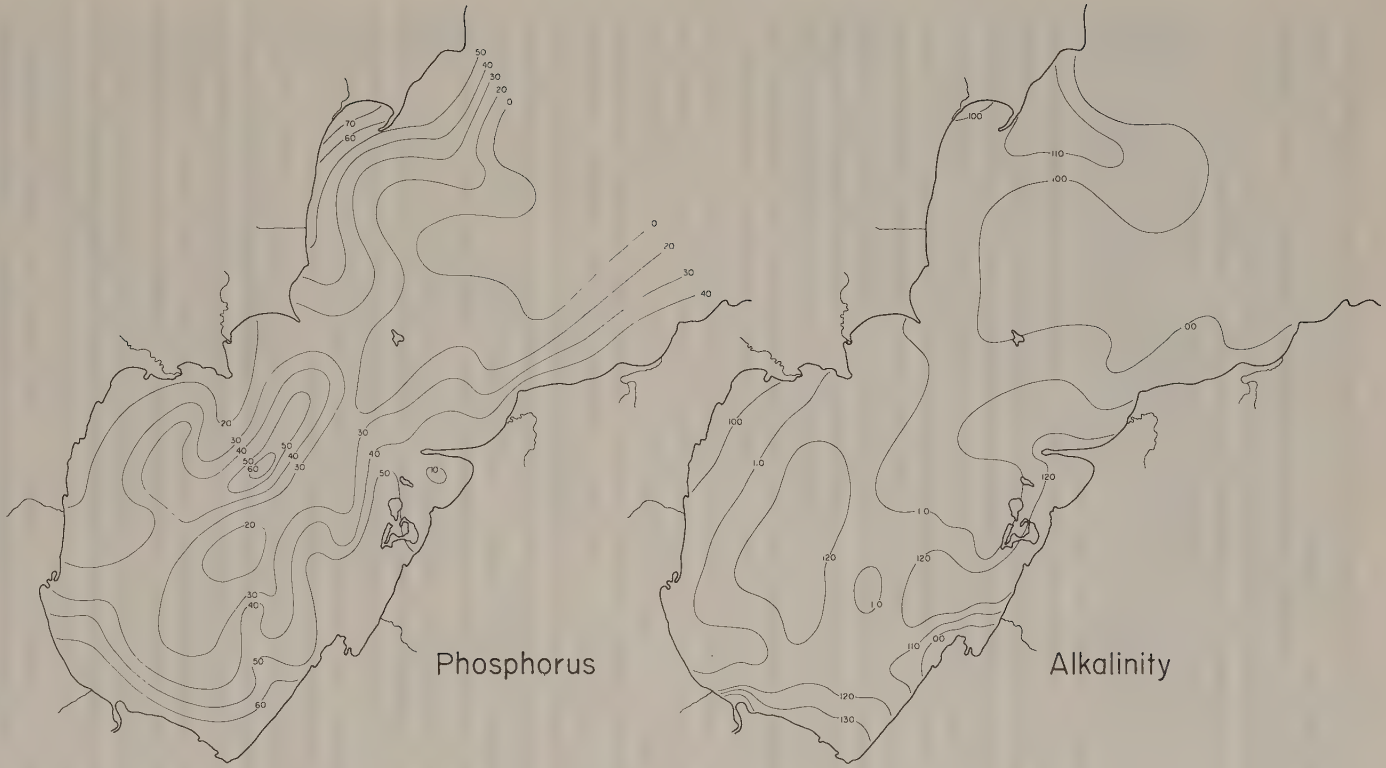
4.5
0 1 2 3 4 5
STATUTE MILES

Magnesium

Potassium


50
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40
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30
40
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60
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40
50
10
20
30
40
50
60
Phosphorus
100
110
100
00
100
1.0
120
1.0
120
1.0
120
110
00
120
130
Alkalinity

Figure 10. Distribution of potassium and magnesium (ppm), phosphorus (ppb), and alkalinity (ppm $CaCO_3$) in Saginaw Bay, August 10, 1956.

moving into the bay along the northwest shore and occupied most of the bay mouth.

Recoveries of drift bottles released on August 22 also suggest a counterclockwise circulation (Johnson, 1958). Between August 6 and 26 winds were from the northwest, west, and southwest.

Synoptic Survey III, October 30.—The distribution of sodium during the October 30 survey (Fig. 11) was similar to the sodium distribution on August 10 (Fig. 9). Water with a high sodium content extended from the Saginaw River mouth along the southeast and northwest shores of the inner bay. Low sodium water occupied the center of the bay between these masses. The high sodium water along the southeast shore continued around Sand Point into the outer bay. Sodium concentrations were low off the mouth of the Rifle River. The southern half of the outer bay had sodium concentrations less than 3 ppm and the lowest (2 ppm) were at the southernmost corner of the bay mouth. Sodium concentrations were generally lower throughout the bay in October than in August.

The distributions of calcium, sulfate, and conductivity agreed more closely with that of sodium than during the two previous surveys (Figs. 6, 9, and 11). Conductivity showed a movement of outer bay water into the inner bay between Charity Island and Point Lookout.

The distributions of alkalinity, magnesium, phosphorus, and potassium (Fig. 12) were similar to that of sodium. Potassium and magnesium values in water near the Saginaw River were only slightly higher than concentrations at other points within the inner bay. Consequently, these ions did not show clearly the distribution of river water. An isolated mass of water with a high potassium content occurred halfway between Sand Point and Point Lookout. This area had high concentrations of potassium on June 7 and August 10. The distribution of alkalinity in the inner bay was very similar to that of sodium. Most of the outer bay waters had alkalinity concentrations of less than 100 ppm; distribution differed somewhat from that of sodium.

The distribution of phosphorus differed strongly from that of other properties. The Saginaw River outflow extended northward as a tongue of high phosphorus water (Fig. 12). Water with high phosphorus content also occurred along the west and southeast shores of the inner bay, but this water appeared to be separated from the river outflow by water with a lower phosphorus content. A distinct mass of water with low phosphorus lay along the west shore north of the mouth of the Saginaw River. Low phosphorus water also occupied the center of the inner bay and continued to the outer bay between Charity Island and Point Lookout--similar to the distribution of sodium, sulfate, and conductivity in that area.

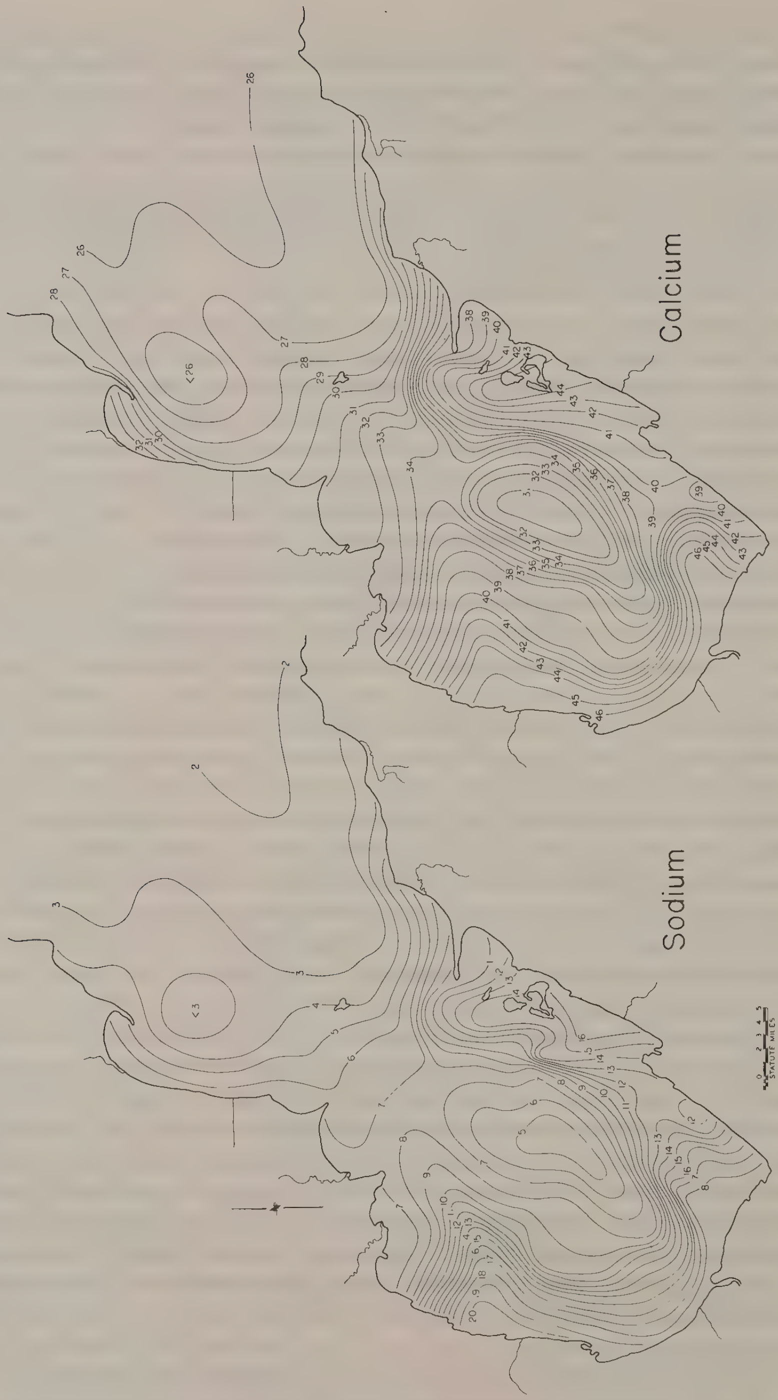
The existence of two masses of water with high ion content along the west and southeast shores suggests that at the time of the October 30 survey the distribution of various properties in the inner bay was determined by a strong injection of Lake Huron water down the center of the inner bay from a point near Charity Island. This intrusion effectively divided the inner bay water into masses along the two shorelines. Clockwise and counterclockwise movements resulting from wind stresses may have been superimposed on this basic pattern.

Summary of the physical and chemical characteristics.—Comparisons of the distribution charts indicate that from June through October concentrations of all chemicals except phosphorus decreased progressively. Also, the sizes of areas of high concentration decreased. Phosphorus concentrations were higher in June and October than in August but water with high phosphorus content occupied a greater area of the bay in August than in June or October. The distribution of phosphorus probably was determined in part by local conditions, especially biological activity.

The large mass of water of high ion content in June may reflect the accumulation of Saginaw River water under the ice during the winter, when wind-induced circulation is minimal. This accumulation of river water is well illustrated by the distribution of chlorides in early surveys of the Michigan Stream Control Commission (1937) which indicated a flow of river water under the ice along the bottom into the deeper part of the inner bay. The direction of this flow was northeasterly, along the west side of Coryeon Reef. On the surveys of March 2-4 and 6-7, 1936, river water appeared as a mass of high chloride water (100-300 ppm), about 2 to 3 miles (3.2 to 4.8 km) wide, which extended at least 20 miles (32 km) from the river mouth. Much higher chloride concentrations were detected throughout the inner bay in the spring of 1936 after the ice had disappeared than in October of 1935.

Currents in the bay were strongly affected by winds. Johnson (1958) concluded from his analysis of drift bottle data: "It appears that the dynamics of the bay are closely related to the highly variable meteorological conditions of this area and that the surface currents are in a continuous state of change. For this reason, we must state specifically under what conditions any particular surface-current pattern was found." Evidence from the present study and from earlier studies by the Michigan Stream Control Commission (1937) suggests that northeast, east, and southeast winds produce a clockwise circulation, and west and southwest winds a counterclockwise circulation.

Surveys by the Michigan Stream Control Commission in 1935 and 1936 provide good examples of the circulation established by


Calcium
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44
45
46
Sodium
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STATUTE MILES

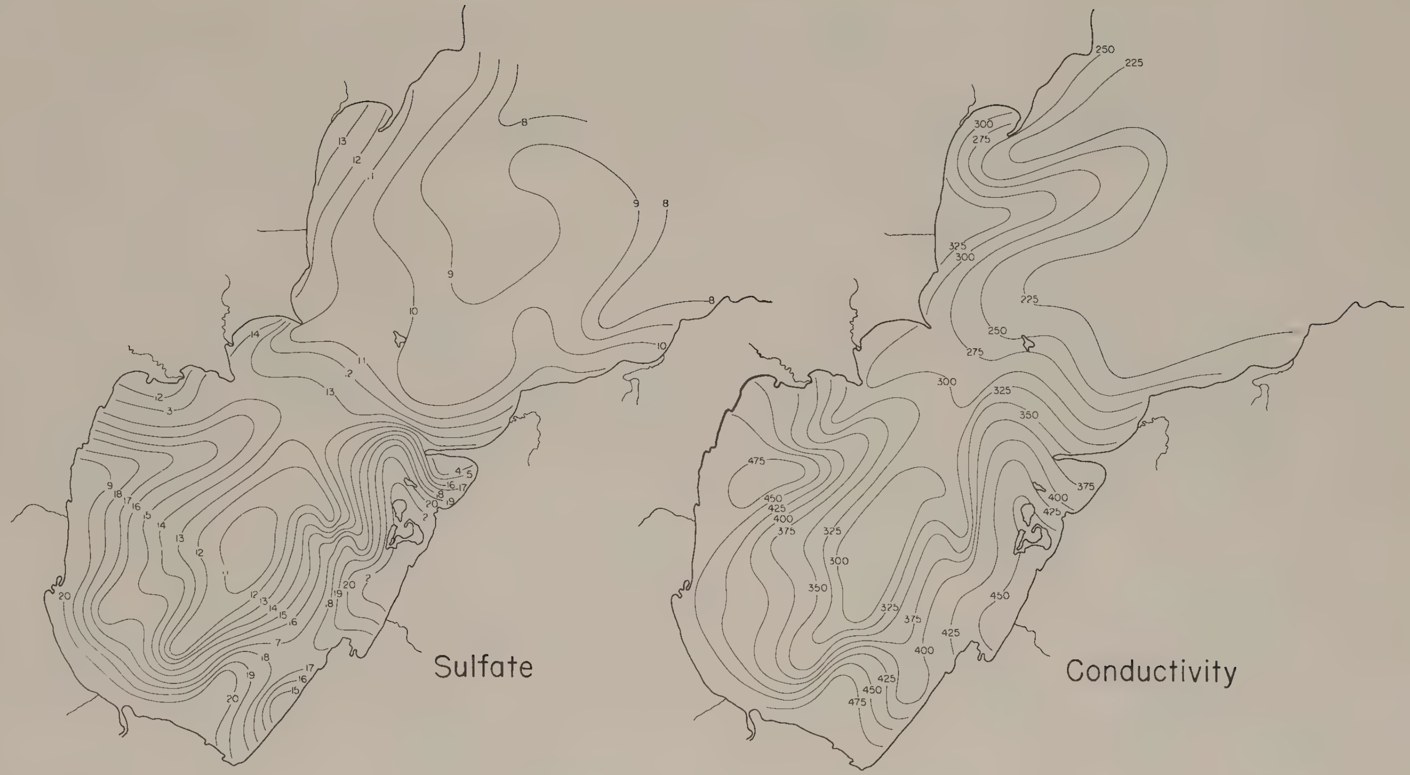
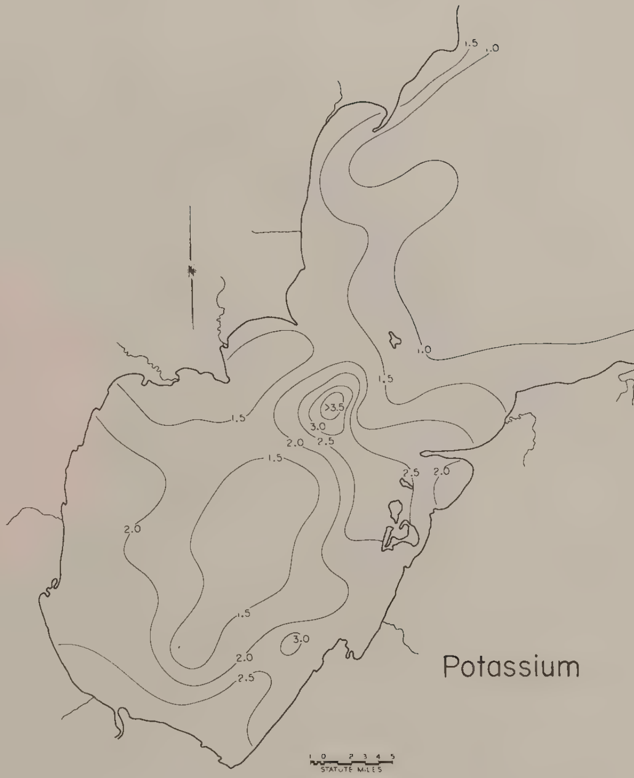

Sulfate
Conductivity

Figure 11. Distribution of sodium, calcium and sulfate (ppm), and conductivity (μmhos at 18° C) in Saginaw Bay, October 30, 1956.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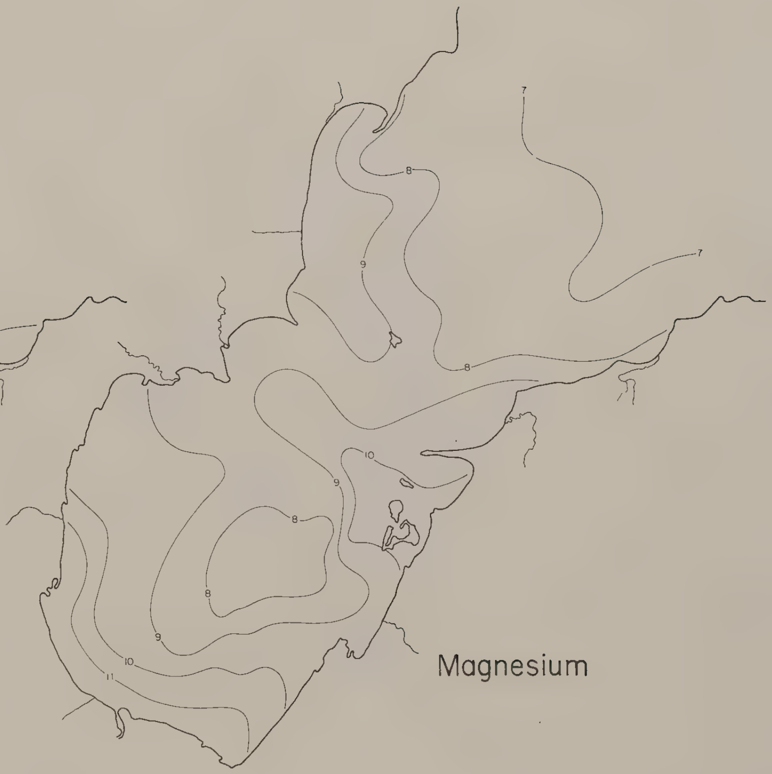
STATUTE MILES

Potassium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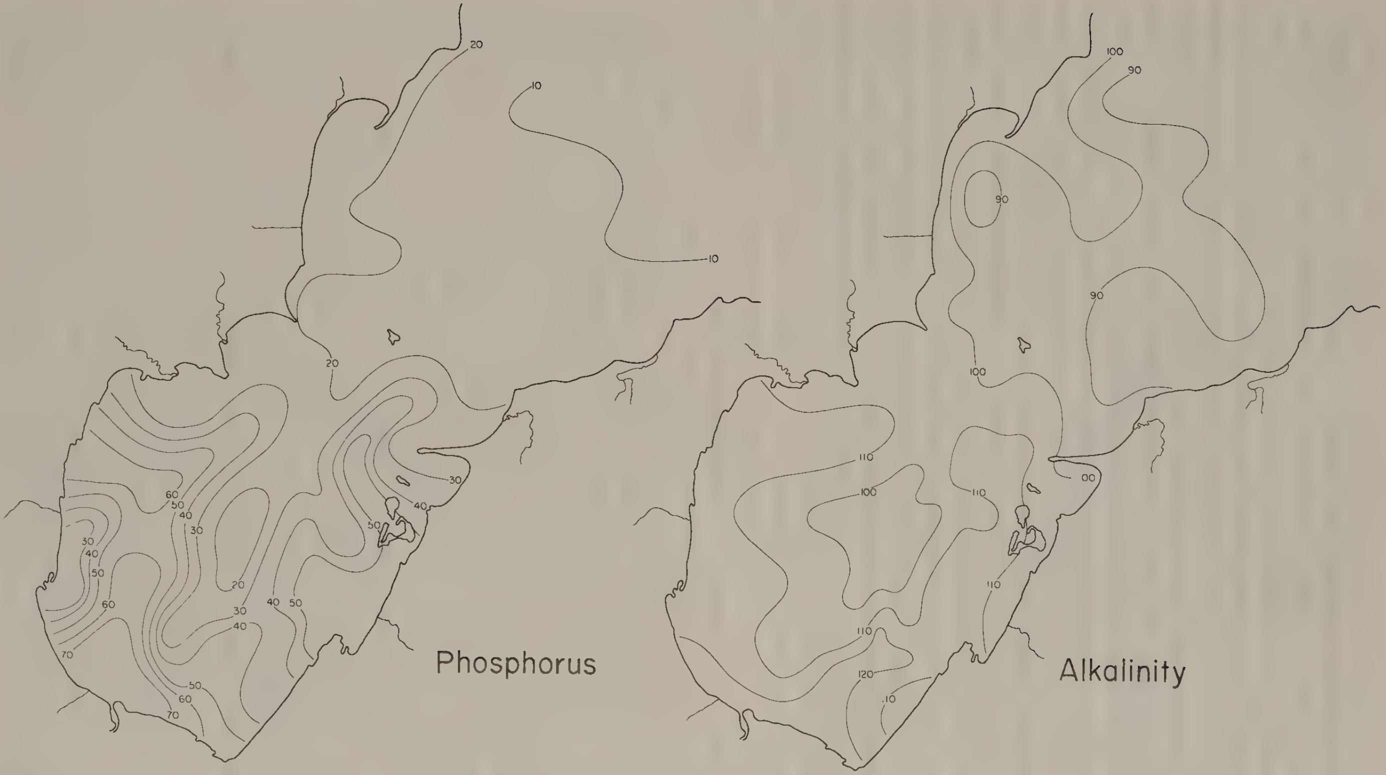
11

Magnesium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70
50
60
70
Phosphorus
100
90
90
90
100
110
100
110
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110
110
120
.10
Alkalinity

Figure 12. Distribution of potassium and magnesium (ppm), phosphorus (ppb), and alkalinity (ppm $CaCO_3$) in Saginaw Bay, October 30, 1956.

different winds. Winds predominantly from the northeast on May 12-24, 1935, were followed by a pronounced clockwise circulation indicated by the results of the surveys on May 13-18 and May 20-24, 1935. Saginaw River water extended from the river mouth along the west and northwest shore of the inner bay and entered the outer bay between Point Lookout and Charity Island. Low chloride water of the outer bay protruded into the inner bay around Sand Point and extended along the southeast shore. Winds from the north, northeast, and southeast during June 7-21, 1936, also produced a clockwise circulation as shown by the survey on June 22-25. A counterclockwise circulation that resulted from southwest and northwest winds during June 19-28, 1935, was evident from the distribution of chlorides in the surveys of June 24-28 and July 1-4. Saginaw River water extended from the river mouth along the southeast shore of the inner bay. Outer bay water penetrated the inner bay between Point Lookout and Charity Island. Winds from the northwest October 18-31, 1935, and from the southwest May 17-27, 1936, also produced a counterclockwise circulation as shown by surveys of October 28-30, 1935, and May 25-27, 1936.

It appears that circulation of bay water can be changed from clockwise to counterclockwise by a shift in wind direction in as short a time as 4 days. The survey of August 10, 1956, suggests that a clockwise circulation existed earlier although counterclockwise circulation was being established by August 10. Winds had been from the northeast, east, and southeast July 15-August 5, but had shifted to southwest and west August 6-10. Similar examples can be found in data of the Michigan Stream Control Commission (1937); the chloride distribution during the survey of June 10-14, 1935, suggests establishment of a counterclockwise circulation after an earlier period of clockwise circulation. Moderate to strong winds were from the southwest and west June 2-8, 1935.

Although it seems clear that the local winds over Saginaw Bay have a strong influence, the relationship of the circulation of the bay to the larger circulation of Lake Huron has not been explored. It cannot be assumed that the larger and presumably stronger inertial current system of Lake Huron does not at times upset or modify the local water movement of Saginaw Bay, particularly when bay currents are weak compared with currents of Lake Huron. This situation is suggested by occasional injections of lake water into the deeper portion of the inner bay through the deep channel between Point Lookout and Charity Island.

The evidence of deflection of the Saginaw River to the right after it enters the bay in every period of this study reflects the effect of the Coriolis influence on a river entering an estuary. The more usual occurrence of higher concentrations of the various ions along the Coryeon Reef or the southeast shore of the inner bay and the south shore of the outer bay indicate clearly that the Coriolis force has a strong influence on the general circulation of the bay. The frequent modification of this influence by wind or injection of Lake Huron water which cause deflection and isolation of river water in various directions are major factors of mixing within the bay. The surveys show that the degree of mixing of Saginaw River water is highly variable particularly in the outer bay where it usually moves into Lake Huron along the south shore around Point Aux Barques under the Coriolis influence of the open lake.

Little similarity existed between the distribution of temperatures (Fig. 2) and other water properties (Figs. 6-12) within the inner bay. The distribution of temperature was similar to other properties on June 7 and August 10 in the outer bay, when the outer bay water with its low ion content also had low temperatures and the warm water of the inner bay had a high ion content. By October 30, however, temperatures were too unfform throughout the bay for any similarity with the distribution of other properties to persist.

Exchange of Saginaw River and Lake Huron Waters in Saginaw Bay

Circulation in marine estuaries has been studied from data on the rate of inflow of freshwater and its distribution in the estuary. From these data estimates can be made of the net seaward transport of river water, the time required for river water to move through the estuary, and the magnitude of the counter current moving into the estuary (Ketchum, 1950, 1953). Low salinity or some other characteristic of river water serves as a tracer. Consequently, it is necessary to have reasonably accurate estimates of the average concentration of the tracer to differentiate river water from sea water. This method assumes that without the river inflow the embayment would have the same salinity as the open sea and that any decrease in salinity can be attributed to river water.

Synoptic surveys of the Saginaw Bay in 1956 provided information on the distribution of river water for estimates of flushing rate, lakeward transport of river water, and exchange between lake and river water. As in marine estuaries, the river water can be used as a tracer, but the salinity relation is reversed; the water of high salinity from the Saginaw River flows out of the bay and the low salinity water from Lake Huron enters the bay. The situation in Saginaw Bay is somewhat more complex than that in the marine estuary because the salt content of the diluting water (Lake Huron), as well as that of the Saginaw Bay and River, must be considered. Furthermore the salt content and the volume of river discharge varied seasonally. Despite these complications the methods used by Tully (1949), Ketchum (1950), and Ketchum, Redfield, and Ayers (1951) can be used to evaluate the circulation of this freshwater bay.

The average salt content of Saginaw Bay was much lower than the river, and was closer to that of Lake Huron. This condition indicated that an appreciable exchange of Saginaw River and Lake Huron water must take place.

The volume of Saginaw River flow and its chemical content varied throughout the year. Although the discharge of the river and its ion content appeared to vary inversely, this relationship was unpredictable. Chloride varied more than 200 ppm in a week. Consequently, records of salt content, as well as river flow, were required.

A gaging station was not maintained on the Saginaw River proper, but discharge records were available for all of the main tributaries. The flow of the Saginaw River, as used in this study, is the combined flow of the Shiawassee, Bad, Flint, Cass, and Tittabawassee Rivers. Data used were those recorded at Fergus, Brant, Fosters, Frankenmuth, and Midland, Michigan (U.S. Geological Survey, 1958, 1959). From these data the average daily discharge of the Saginaw River was calculated for the 30-day period preceding the 2nd day of each synoptic survey (Appendix Table A-6). The average daily flow before the first survey in June (993 million cubic feet or 28 million cubic meters) was 5 to 11 times higher than in August or October. This greater discharge was due to the spring thaw and May rains. Stream flow declined from the end of May to October; the average daily flow before the third survey on October 30 was 86 million cubic feet (2.4 million m^3). The annual average discharge was 292 million cubic feet (8.3 million m^3) per day.

Fourteen small rivers and a number of creeks flow into Saginaw Bay, but most of the larger rivers, except for the Rifle and Au Gres, have a mean discharge of less than 60 cubic feet (1.7 cubic meters) per second during most of the year. The combined average daily flow of the Rifle, Au Gres, and Kawkawlin Rivers for the 30 days preceding the first survey, which included their flood periods, was about 8% of the flow of the Saginaw River. These rivers have a lower ion content than the Saginaw River (Appendix Table A-5) and therefore have a diluting influence.

Sodium was selected as the best tracer for study of the distribution of Saginaw River water in the bay, because it is least likely to be removed by chemical precipitation or by biological uptake. The concentration of sodium in the Saginaw River was not determined during our surveys and evidently had not been measured in the past. The chloride content of the river, however, had been determined routinely for many years by the Dow Chemical Company and data were available for a period preceding each survey.

To determine the relationship between sodium and chloride for the Saginaw River, the sodium content was measured for weekly water samples from the Saginaw River from November 1959 to March 1960. These values were plotted against weekly chloride determinations made by the Dow Chemical Company over the same period. The relationship was described by $Na = 17.7 + 0.187\ Cl$. Subsequently the sodium concentrations of river water were calculated from the average chloride concentration measured by the Dow Chemical Company for the 30-day period before each survey of 1956. The average chloride ranged from 152 ppm before the first survey to 346 ppm before the third survey. Corresponding sodium values were 46 ppm and 82 ppm (Appendix Table A-6).

The average sodium content of the bay during each survey was estimated by superimposing a transparent plastic grid on charts[4] on which isopleths of sodium were drawn. The grid consisted of 1-inch squares ($6.45\ cm^2$); hence, each square represented a surface area unit of 100×10^6 square feet ($9.29 \times 10^6\ m^2$). The volume of each unit was determined by placing the grid on a chart of depth contours. Calculations were made of the quantity of sodium within the volume of each unit for each of the three surveys. From these data water volumes, total sodium, and the average sodium content (ppm) were calculated for each of three zones delineated by the transects A-B, C-D, and E-F (Fig. 1). Zone 1 is closest to the Saginaw River mouth, zone 2 is the area that lies between lines A-B and C-D, and zone 3 is the outer bay. The area of bay cross-sections at each transect and the corresponding average sodium content of water across the transect were calculated also from the values of grid units or fractions thereof bisected by the transects (Table 3).

The proportion of Saginaw River water in any sample, water column, or in the entire bay can be calculated from the average sodium content. It can be assumed that Saginaw River and Lake Huron water were mixing in the bay during the surveys. Vertical differences in the distribution of the major ions were slight. Consequently, the surface concentration of sodium was considered representative of the sodium content of an entire water column. The volumes of river water (V_r) and lake water (V_h) were derived from the relationship:

$$V_r\, S_r + V_h\, S_h = (V_r + V_h)\, S_o$$

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[4] These charts were drawn from Corps of Engineers, U.S. Army, Lake Survey Chart No. 52, revised 1955; scale 1 inch = 10,000 feet.

where S_o is the observed sodium content, S_h the sodium content of Lake Huron water, and S_r the average concentration of sodium in the Saginaw River. The sodium values selected as representative of the lake and the river obviously were critical in the computations. A sodium concentration of 2.0 ppm was taken as representative of Lake Huron water, although the lowest sodium value reported by Allen (1964) was 2.21 ppm.

Table 3. Volume of zones and areas of cross-sections

[See Fig. 1 for boundaries of zones and locations of cross-sections]

Zone and section	Volume of zone (billion cu. ft.)	Area of cross-section (million sq. ft.)
Zone 1, A-B	122.8	2.051
Zone 2, C-D	136.1	1.155
Zone 3, E-F	694.7	12.259
Total	953.6	-

The time required for the daily discharge of a river to move through an estuary is the flushing time. It is the ratio of the volume of accumulated river water in the estuary to the volume introduced daily. The flushing times for zones 1, 2, and 3 of Saginaw Bay were calculated from data of each survey (Table 4). During the period of peak river discharge, the 30 days preceding the June 7 survey, 114 days would be required for a 1-day accumulation of river water to move through the bay. Flushing time increased as river discharge decreased in August and October. The average river discharge in October was about one-tenth that of May 9-June 7 (Appendix Table A-6) but the October flushing time was only about three times longer than that for June.

Two factors influence calculations of the flushing rates—the morphology of the bay and the varying sodium content of the river. Point Lookout, Sand Point, and the shoal area extending from the southeast shore to Charity Island (Fig. 1) evidently limit exchange between the inner and outer bay. The effect of decrease in river flow on flushing time is more pronounced in the inner bay (zones 1 and 2) than in the outer bay (Table 4). The flushing time in the inner bay increased by a factor of 3.8 between June and October but it increased only 2.4 times in the outer bay. The sodium concentration of the river increased as the discharge decreased. This relationship causes the fraction of river water in the bay to decrease as the sodium content of the river increases and results in underestimation of the flushing time as river flow decreases.

Table 4. Average sodium content, percentage of river water in zones, and flushing times for the three zones of Saginaw Bay, 1956

Date and zone	Average sodium (ppm)	Percentage of river water	Flushing time (days)
June 7			
1	15.0	29.5	37
2	13.8	26.8	37
3	4.5	5.7	40
Total			114
August 10			
1	15.6	19.9	131
2	9.3	10.7	78
3	3.3	1.9	71
Total			280
October 30			
1	11.2	11.4	162
2	8.0	7.5	118
3	3.0	1.2	96
Total			376
Annual average[1] entire bay	5.9	5.7	186

[1] Based on the average sodium concentration in the entire bay during the three surveys and the average annual discharge of the Saginaw River.

The rate of lakeward transport of Saginaw River water at transects A-B, C-D, and E-F of Saginaw Bay (Fig. 1) was calculated for each survey (Table 5). Calculations were based on the average daily river flow; consequently transport rates are expressed in feet per day.

Although lakeward transport decreased with decreasing river discharge, change in lakeward transport was not of the same magnitude as the change in river flow. Transport ranged from 619 to 2,294 feet (188.7 to 699.2 m) per day for section A-B, and from 1,410 to 3,000 feet (429.8 to 914.4 m) per day for section E-F. The corresponding river discharge ranged from 86 to 993 million cubic feet (2.4 to 28 million m^3) per day. The discrepancy is due to the greater percentages of river water in the areas of the cross

Table 5. Lakeward transport of Saginaw River water and entrained lake water for three sections of Saginaw Bay, 1956

	Section A-B			Section C-D			Section E-F		
	June 7	Aug. 10	Oct. 30	June 7	Aug. 10	Oct. 30	June 7	Aug. 10	Oct. 30
Percentage of river water	21.1	11.6	6.8	23.0	7.5	5.8	2.7	1.0	0.5
Lakeward transport (ft. per day)	2,294	782	619	3,737	2,147	1,290	3,000	1,517	1,410
Total volume moving lakeward (million cu. ft. per day)	4,705	1,604	1,270	4,317	2,480	1,490	21,954	10,510	9,839
Transport ratio (total volume to river volume)	4.7	8.6	14.7	4.3	13.3	17.2	22.1	56.5	113.9

sections during the first survey (Table 5). Change in river discharge had the greatest influence on the rate of lakeward transport in the innermost part of the bay. This situation has been observed in marine estuaries (Ketchum, 1953).

The lakeward transport through section C-D was greater than that for transects A-B in all surveys and greater than transect E-F except on October 30 (Table 5). This transport through section C-D was to be expected since the area of this transect is only 56.3% of section A-B and only 9.4% of section E-F. The transport through section E-F in October was greater than during earlier surveys because the river water made up a smaller fraction of the area of the cross section.

The decrease in the ion concentrations from the river to the bay mouth was caused by mixing of river water with progressively greater amounts of water from Lake Huron. Consequently, the river flow entrained an increasing amount of lake water as it moved through the bay. The exchange of lake and bay water must be extensive since the average sodium content of the bay was low and decreased from 7.2 ppm in June to 4.7 ppm in October (Table 4) even though the ion content of river water remained high.

Acknowledgments

The assistance of many employees of the Michigan Department of Conservation and the U.S. Bureau of Commercial Fisheries is gratefully acknowledged. Dr. Glenn Flittner drew the contoured distributions of temperature, conductivity, and chemical constituents. Mr. William Cristanelli prepared most of the figures.

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APPENDIX

Table A-1. Thermal and chemical data for various stations in Saginaw Bay, 1956

Station and date	Time (EST)	Depth (meters)	Temperature (°C)	Dissolved oxygen		pH
				ppm	percentage saturation	
Station 42						
June 29	14:00	0	19.1	10.1	112	8.3
		5	19.1	8.4	94	8.3
		8	18.9	8.4	93	8.3
July 18	11:00	0	20.1	9.1	103	8.4
		5	20.1	9.1	103	8.4
		9	18.3	8.9	97	8.3
August 10	11:00	0	21.0	8.5	98	8.3
		5	21.0	8.6	99	8.3
		9	20.9	8.5	98	8.3
August 30	11:00	0	20.1	8.7	98	8.3
		5	20.0	8.8	100	8.3
		9	19.8	8.5	96	8.2
September 21	10:30	0	13.9	9.3	93	8.1
		5	13.9	9.0	90	8.0
		9	13.9	8.6	86	8.0
October 12	12:20	0	12.0	10.2	97	8.0
		5	11.9	10.0	95	8.0
		9	11.8	10.1	96	8.0
October 30	11:30	0	10.5	9.5	88	7.9
		5	10.5	9.7	90	8.0
		10	9.5	9.7	88	7.9
Station 45						
June 29	11:50	0	15.6	9.7	100	8.3
		7	12.4	10.4	101	8.3
		15	9.3	11.2	101	8.1
July 18	9:00	0	17.0	9.2	98	8.3
		5	17.0	9.2	98	8.3
		15	13.4	10.1	100	8.3
August 10	9:00	0	18.8	9.0	100	8.1
		9	18.8	8.9	99	8.0
		14	14.6	10.1	103	8.0
August 30	9:00	0	19.1	8.9	99	8.3
		5	19.1	9.0	100	8.3
		14	15.2	9.6	98	8.1
September 21	8:35	0	14.2	9.2	93	8.0
		5	14.2	9.2	93	8.0
		14	14.2	9.2	93	8.0
October 12	10:15	0	11.5	9.9	94	7.9
		5	11.6	10.0	95	7.8
		17	11.6	10.1	96	7.8
October 30	9:40	0	10.7	8.4	78	8.0
		5	10.7	7.9	73	8.1
		15	10.4	8.5	78	7.8
Station 60						
June 10	11:00	0	18.3	9.1	99	8.1
		5	16.2	8.8	92	8.1
		10	13.3	7.3	72	7.9
June 20	13:30	0	19.9	7.8	86	8.1
		4	19.8	7.7	86	8.1
		9	16.0	6.3	66	7.9
July 1	10:45	0	19.5	9.5	106	8.3
		5	18.8	8.6	95	8.3
		9	15.8	9.5	98	8.3
July 12	15:15	0	19.2	9.1	102	8.4
		5	18.6	8.9	98	8.4
		9	17.8	8.4	92	8.3
July 22	11:00	0	20.6	8.6	99	8.2
		5	20.6	8.5	97	8.2
		10	19.7	8.2	92	8.0

Continued

Table 1. (Continued)

				Dissolved oxygen		
Station and date	Time (EST)	Depth (meters)	Temperature (°C)	ppm	percentage saturation	pH
August 1	10:20	0	21.1	8.0	92	8.2
		5	20.9	8.0	92	8.2
		10	20.8	7.8	89	8.2
August 12	11:30	0	22.0	8.3	98	8.3
		5	21.4	8.6	100	8.3
		10	21.3	8.3	97	8.2
August 22	12:10	0	20.3	8.5	97	8.3
		5	20.3	8.3	95	8.3
		9	20.2	8.3	95	8.3
September 1	11:20	0	20.3	8.7	100	8.3
		5	20.3	8.7	100	8.3
		9	18.7	7.2	80	8.1
September 12	12:00	0	19.0	8.6	96	8.1
		5	18.7	8.6	95	8.1
		10	18.5	8.3	92	8.1
September 23	11:30	0	15.0	8.9	92	8.1
		4	15.0	8.5	87	8.1
		9	15.0	8.9	92	8.1
October 3	12:35	0	15.0	9.2	94	8.2
		5	14.7	9.6	98	8.1
		9	14.6	9.3	94	8.1
October 13	12:30	0	12.5	9.4	91	8.0
		5	12.4	9.4	91	8.0
		10	12.0	8.8	84	8.0
November 3	13:50	0	12.2	8.6	83	8.0
		5	12.1	8.5	82	7.9
		10	12.0	8.6	82	7.9
November 14	12:15	0	8.3	10.4	92	8.0
		5	8.2	10.6	93	8.0
		9	7.9	10.3	89	8.0
Station 61						
June 10	9:00	0	15.2	10.4	106	8.1
		5	10.4	11.3	104	8.1
		10	8.2	11.7	103	8.0
June 20	16:15	0	17.4	9.2	98	8.3
		5	17.3	9.2	98	8.3
		14	13.8	9.3	93	8.3
July 1	9:00	0	16.0	9.7	102	8.3
		5	15.6	9.8	102	8.3
		14	8.2	11.4	100	8.1
July 12	17:20	0	16.9	9.4	99	8.3
		5	16.8	9.5	100	8.3
		14	7.7	11.0	96	8.1
July 22	9:00	0	19.2	8.8	98	8.3
		9	18.8	9.1	100	8.3
		14	16.2	9.3	97	8.0
August 1	12:30	0	19.3	9.1	101	8.2
		5	19.3	9.1	101	8.1
		14	18.8	9.0	100	8.1
August 12	9:00	0	19.9	8.9	101	8.2
		5	19.1	8.9	99	8.1
		14	11.1	10.9	102	8.0
August 22	14:10	0	19.4	9.0	101	8.3
		5	19.4	9.0	101	8.3
		14	16.6	9.4	100	8.3
September 1	9:30	0	19.8	8.9	100	8.1
		5	19.6	8.7	98	8.1
		10	16.4	9.1	97	8.1
September 12	14:00	0	17.7	9.1	98	8.2
		5	17.2	9.3	99	8.2
		15	14.3	9.8	98	8.1

Continued

Table 1. (Continued)

Station and date	Time (EST)	Depth (meters)	Temperature (°C)	Dissolved Oxygen		pH
				ppm	percentage saturation	
September 23	9:40	0	14.4	8.6	87	8.1
		5	14.4	8.7	88	8.1
		14	14.4	9.0	92	8.1
October 3	14:45	0	14.2	9.8	98	8.0
		5	14.0	10.2	101	8.1
		14	14.2	9.9	100	8.0
October 13	10:15	0	11.8	10.3	98	7.9
		5	11.8	10.3	98	7.8
		16	11.7	10.3	98	7.8
November 3	9:30	0	11.5	9.8	93	8.0
		5	11.4	9.7	92	8.0
		14	11.4	9.4	89	8.0
November 14	15:10	0	7.8	10.0	87	8.0
		5	7.7	10.0	87	8.0
		15	7.6	10.3	88	8.0
Station 62						
June 5	17:00	0	9.2	11.5	103	7.9
		15	7.1	11.9	102	7.9
		30	6.9	11.9	102	7.9
June 21	9:30	0	17.7	9.1	98	8.1
		15	8.2	12.1	107	8.1
		30	5.8	11.7	97	7.9
July 13	9:40	0	16.2	9.5	100	8.3
		15	10.3	11.0	102	8.3
		30	5.4	11.3	93	7.9
August 2	9:40	0	17.5	9.4	102	7.9
		15	16.3	9.7	102	7.9
		30	10.8	11.6	108	7.8
August 24	10:40	0	18.2	9.1	99	8.2
		15	18.1	9.1	99	8.2
		30	9.6	11.0	100	7.9
September 13	9:20	0	17.7	9.1	98	8.1
		15	15.6	9.4	97	8.1
		30	7.8	11.0	96	7.6
October 5	9:30	0	13.2	10.0	98	8.1
		15	13.2	10.0	98	8.1
		30	13.2	9.8	96	8.0
October 27	9:30	0	11.4	9.6	91	8.0
		15	11.4	9.6	91	8.0
		30	11.4	9.7	91	8.0

Table A-2. Chemical characteristics of Saginaw Bay, June 7, 1956

Station	Depth (meters)	Calcium (ppm)	Magnesium (ppm)	Potassium (ppm)	Sodium (ppm)	Total alkalinity (ppm $CaCO_3$)	Phosphorus (ppm)	Sulfate (ppm)	Specific conductance (µmhos 18° C)
1	0	56	11.7	3.5	14.0	142	0.054	41	530
2	0	59	12.5	4.3	18.6	142	0.050	41	629
3	0	71	13.0	5.1	23.8	144	0.066	43	702
4	0	80	13.3	5.5	25.0	144	0.068	42	800
5	0	54	11.1	3.6	17.0	120	0.049	27	536
6	0	55	10.1	3.7	17.0	118	0.045	23	537
7	0	55	11.1	3.8	16.7	118	0.045	23	546
8	0	49	9.9	2.9	13.8	116	0.047	21	462
9	0	54	11.3	3.8	13.5	131	0.039	37	550
10	0	63	12.0	4.2	16.2	140	0.041	38	591
11	0	68	12.4	4.4	18.2	135	0.046	37	632
12	0	52	11.8	4.2	16.8	137	0.044	36	585
13	0	59	12.3	3.7	15.9	130	0.052	31	587
14	0	56	11.2	3.7	16.4	130	0.043	28	549
15	0	52	9.1	3.7	16.1	129	0.042	23	517
16	0	43	9.9	2.6	12.6	110	0.038	19	443
17	0	42	11.1	2.5	11.5	106	0.028	17	396
18	0	38	9.7	1.9	9.7	106	0.027	14	367
19	0	39	9.2	1.8	8.7	106	0.024	17	-
21	0	52	10.1	3.4	14.5	113	0.043	33	520
22	0	58	11.4	4.0	19.0	109	0.019	28	561
23	0	61	11.6	4.3	21.3	112	0.016	29	629
24	0	53	10.3	3.8	18.0	98	0.014	21	542
25	0	51	10.6	3.5	17.2	109	0.022	21	523
26	0	48	10.1	3.1	15.0	112	0.019	24	497
27	0	43	9.5	2.6	12.0	97	0.018	17	442
28	0	41	9.4	2.2	11.2	111	0.019	18	413
29	0	41	9.2	2.0	10.7	106	0.033	18	400
30	0	52	10.3	3.7	18.0	113	0.019	24	553
31	0	58	10.3	3.2	14.3	122	0.020	36	532
32	0	50	11.0	3.1	15.7	115	0.021	21	520
33	0	38	9.8	2.1	10.1	99	0.018	15	383
34	0	34	8.5	1.6	7.6	94	0.016	13	328
35	0	41	8.6	4.2	11.2	100	0.016	15	426
36	0	41	10.6	2.4	11.2	104	0.015	17	422
37	0	45	9.9	2.8	14.6	108	0.018	19	464
38	0	40	9.6	2.4	11.6	101	0.018	18	421
39	0	40	9.7	2.1	10.4	99	0.019	16	396
41	0	43	9.0	2.3	10.1	103	0.018	16	394
42	0	36	8.9	1.8	9.1	102	0.009	17	358
42a	0	25	7.4	1.1	4.6	98	0.010	15	271
43	0	29	8.2	1.3	5.1	100	0.011	13	288
44	0	35	7.7	1.4	5.8	100	0.009	13	299
45	0	30	7.3	1.0	3.8	93	0.014	11	255
	16	27	7.3	1.8	3.3	91	0.018	11	226
46	0	29	7.3	0.9	2.4	93	0.011	10	231
	14	27	7.1	0.8	2.7	95	0.016	8	237
47	0	31	6.9	1.8	3.8	100	0.012	13	265
48	0	35	9.2	1.7	6.4	100	0.016	14	308
49	0	40	9.2	2.4	8.1	100	0.012	15	347
49a	0	34	10.6	1.7	4.8	94	0.016	13	278
50	0	28	10.2	1.3	3.0	90	0.013	11	234
	28	32	7.2	2.5	2.7	96	0.019	8	224
50a	0	27	7.3	0.9	2.6	94	0.014	11	206
51	0	27	7.0	2.1	2.3	92	0.015	9	227
	26	26	6.8	0.8	2.4	91	0.010	9	227
51a	0	27	7.0	1.5	2.4	100	0.010	9	217
52	0	28	8.0	0.9	2.4	94	0.012	9	233
53	0	29	9.6	1.1	2.7	92	0.009	9	238

Table A-3. Chemical characteristics of Saginaw Bay, August 10, 1956

Station	Depth (meters)	Calcium (ppm)	Magnesium (ppm)	Potassium (ppm)	Sodium (ppm)	Total alkalinity (ppm Ca CO_3)	Phospohrus (ppm)	Sulfate (ppm)	Specific conductance (μmhos 18° C)
1	0	51	11.1	3.5	18.8	120	0.060	27	510
2	0	51	16.7	3.6	21.8	119	0.049	28	557
3	0	52	10.9	3.6	21.8	113	0.038	27	559
5	0	42	9.0	2.4	11.7	119	0.030	18	411
6	0	46	9.8	3.2	14.6	110	0.032	21	456
7	0	49	10.0	3.0	18.8	111	0.048	23	482
8	0	47	10.4	3.0	19.9	112	0.040	24	512
9	0	48	10.6	3.4	19.0	100	0.045	27	525
10	0	44	10.0	4.5	15.2	118	0.046	23	448
11	0	44	10.4	3.5	16.0	117	0.039	22	456
12	0	43	10.5	2.6	15.2	113	0.044	24	440
13	0	38	9.3	1.8	10.4	110	0.029	17	369
14	0	38	9.6	2.1	10.6	115	0.028	17	373
15	0	38	9.8	1.9	10.0	115	0.024	17	373
16	0	43	10.5	2.4	14.2	124	0.029	19	433
17	0	47	10.1	4.4	18.4	123	0.029	23	486
18	0	48	11.4	3.0	20.3	113	0.032	23	510
19	0	44	10.0	2.5	14.3	108	0.025	20	433
21	0	39	9.9	2.7	10.9	109	0.050	19	394
22	0	40	8.6	2.1	9.5	112	0.034	20	383
23	0	37	8.5	2.0	7.8	110	0.040	16	333
24	0	35	8.2	2.0	6.0	110	0.034	14	315
25	0	36	8.5	1.9	8.3	107	0.025	17	339
26	0	37	8.8	2.3	8.3	108	0.064	16	348
	10	36	9.2	1.6	8.0	99	0.022	15	349
27	0	44	10.4	2.9	13.1	118	0.023	21	450
	7	41	9.6	2.8	12.0	109	0.035	21	433
28	0	40	9.7	4.5	11.1	114	0.037	19	416
29	0	38	9.3	3.1	11.2	109	0.027	18	421
30	0	42	10.0	2.5	13.1	108	0.050	21	441
31	0	44	10.4	3.0	13.9	121	0.014	23	483
32	0	41	9.1	2.5	12.2	115	0.038	22	420
33	0	37	8.5	2.1	10.0	112	0.037	17	377
34	0	35	9.1	4.0	7.1	110	0.015	16	352
35	0	32	8.5	1.5	6.4	107	0.031	16	310
36	0	31	9.0	1.6	5.4	104	0.039	13	292
	8	32	7.5	1.6	5.6	99	0.015	14	298
37	0	34	9.0	1.5	6.5	110	0.026	15	310
	9	30	8.8	1.4	5.4	97	0.017	13	290
38	0	38	9.1	2.0	8.6	111	0.025	17	367
39	0	39	8.8	2.9	8.2	111	0.023	21	377
41	0	35	7.8	1.5	5.0	102	0.032	14	280
42	0	31	7.6	1.5	4.9	99	0.019	13	280
	5	31	8.3	1.5	4.8	99	0.017	13	282
	9	31	8.5	1.4	5.5	100	0.014	13	280
42a	0	32	8.3	1.6	5.3	101	0.016	13	293
43	0	31	7.5	1.2	4.5	96	0.012	12	272
44	0	28	6.9	1.5	3.9	96	0.009	12	253
45	0	28	7.0	0.9	2.8	96	0.014	11	232
	9	27	7.3	0.8	2.8	100	0.015	10	233
	14	26	7.0	1.0	2.6	95	0.057	10	220
46	0	30	7.8	1.1	4.2	108	0.031	13	274
47	0	32	7.3	1.2	4.8	113	0.069	14	280
48	0	32	8.1	1.2	4.7	100	0.041	13	280
49	0	29	7.6	1.5	3.6	100	0.028	11	256
49a	0	27	7.6	1.1	2.6	98	0.009	10	228
50	0	27	7.1	1.2	2.3	98	0.008	11	223
	24	27	7.1	0.9	2.2	-	0.012	10	217
50a	0	27	7.4	1.0	3.0	106	0.010	11	246
51	0	27	7.6	1.0	3.1	109	0.009	10	243
	23	26	7.4	1.0	2.1	111	0.012	9	222
51a	0	29	7.8	1.2	3.3	100	0.011	11	252
52	0	27	7.0	1.6	2.7	98	0.051	10	239
53	0	27	7.0	1.3	2.7	99	0.053	11	232

Table A-4. Chemical characteristics of Saginaw Bay, October 30, 1956

Station	Depth (meters)	Calcium (ppm)	Magnesium (ppm)	Potassium (ppm)	Sodium (ppm)	Total alkalinity (ppm Ca CO_3)	Phosphorus (ppm)	Sulfate (ppm)	Specific conductance (μmhos 18° C)
1	0	39	10.1	2.3	13.1	107	0.031	15	402
2	0	43	10.5	2.7	16.1	115	0.037	19	440
	3	41	9.7	2.4	16.1	115	0.045	19	-
3	0	46	10.1	2.7	15.7	112	0.043	20	452
4	0	45	10.1	1.5	16.7	122	0.044	19	475
5	0	36	8.8	1.5	7.2	102	0.031	12	320
	4	34	9.0	1.4	7.5	104	0.025	11	-
6	0	37	9.5	2.1	11.6	108	0.068	16	393
7	0	39	9.7	2.3	14.5	113	0.052	16	410
	6	42	10.0	2.2	15.0	111	0.057	17	-
8	0	44	10.4	2.2	16.8	113	0.029	19	429
9	0	41	9.2	2.3	12.3	116	0.051	18	421
10	0	40	9.5	3.0	12.2	116	0.035	17	400
11	0	38	9.2	1.9	10.4	115	0.039	17	369
12	0	37	8.7	1.6	9.1	123	0.040	15	355
13	0	33	8.7	1.5	6.3	102	0.028	13	305
14	0	32	7.6	1.3	5.1	103	0.024	12	284
15	0	33	8.5	1.4	5.7	103	0.023	12	304
	7	33	8.7	1.4	6.3	107	0.029	13	-
16	0	38	8.7	1.8	8.6	108	0.054	15	360
	7	38	9.1	1.7	8.4	112	0.054	15	-
17	0	39	9.4	1.9	9.7	109	0.053	15	375
	6	39	9.8	2.6	10.0	110	0.051	15	-
18	0	44	9.9	2.2	17.0	109	0.049	18	451
19	0	45	9.5	2.3	19.0	112	0.064	19	475
21	0	41	9.8	2.4	13.7	112	0.037	17	421
22	0	40	10.0	2.5	14.2	112	0.036	18	401
23	0	34	7.8	2.0	7.3	111	0.034	13	315
24	0	34	8.1	1.5	6.9	99	0.037	14	315
25	0	32	8.3	1.4	6.0	100	0.027	12	295
26	0	32	8.3	1.3	6.0	100	0.025	12	295
27	0	38	8.9	1.7	9.5	113	0.043	16	369
28	0	35	8.6	1.6	8.1	114	0.027	14	327
29	0	34	8.8	1.2	6.5	110	0.026	13	395
30	0	44	10.2	2.8	14.5	112	0.039	21	438
31	0	39	9.8	2.0	10.9	103	0.029	15	378
32	0	41	9.7	2.1	12.6	114	0.026	19	401
33	0	39	9.0	2.0	10.8	107	0.049	15	383
34	0	32	8.6	1.8	6.3	108	0.026	13	368
35	0	33	8.8	3.6	6.5	103	0.017	13	294
36	0	33	8.8	2.2	6.5	106	0.026	13	295
	9	33	8.3	1.5	7.1	103	0.021	12	-
37	0	31	8.8	1.2	6.3	104	0.016	12	285
	10	31	8.1	1.5	5.3	97	0.022	10	-
38	0	31	8.3	1.2	6.2	106	0.021	11	285
39	0	31	8.6	1.8	7.1	108	0.025	15	305
41	0	29	9.5	1.2	5.2	92	0.019	11	249
42	0	26	8.1	1.3	2.5	84	0.015	10	216
	5	26	7.9	0.8	2.6	92	0.012	9	-
	10	26	10.5	0.8	2.5	88	0.013	8	-
42a	0	26	7.7	0.9	2.3	84	0.013	10	216
43	0	26	7.9	0.8	2.5	92	0.015	9	218
44	0	28	7.6	0.9	3.4	95	0.018	10	239
45	0	25	9.0	1.3	2.4	93	0.015	10	317
	5	26	7.7	0.9	2.6	93	0.014	9	-
	15	25	7.9	0.9	2.7	99	0.016	9	-
46	0	26	7.7	0.9	3.2	92	0.025	11	227
47	0	32	9.3	1.8	6.1	102	0.028	13	296
48	0	27	7.7	1.0	2.9	86	0.013	10	227
49	0	26	7.7	0.9	2.3	92	0.013	8	215
49a	0	26	6.8	0.9	2.0	93	0.014	10	217
50	0	26	7.4	0.9	2.2	93	0.012	9	216
	26	26	6.9	0.8	2.3	90	0.013	9	-
50a	0	26	7.6	0.8	2.6	92	0.013	9	216
51	0	27	7.2	0.9	3.2	98	0.015	9	260
	25	26	7.6	1.2	2.6	92	0.012	9	-
51a	0	26	7.4	0.8	2.6	92	0.011	8	222
52	0	27	7.7	0.8	3.4	93	0.018	10	227
53	0	28	7.6	1.7	3.7	101	0.020	10	248

Table A-5. Mean discharge and chemical composition of three of the larger secondary tributaries to Saginaw Bay

[Discharge is for the water year Oct. 1955 through Sept. 1956]

River	Calcium (ppm)	Sodium (ppm)	Chloride (ppm)	Sulfate (ppm)	Silica (ppm)	Specific conductance (µmhos 18°C)	Mean flow (cfs)
Au Gres	51	3.6	7.3	100	5.8	315	146
Kawkawlin	53	8.7	22.2	73	3.8	332	53
Rifle	34	4.5	10.0	36	7.0	230	290

Table A-6. Saginaw River flow and average sodium content, 1956

Date	Average discharge (million cu. ft. per day)	Average sodium[1] (ppm)	Average chloride[2] (ppm)
May 9-June 7	993	46	152
July 12-August 10	186	70	280
October 1-31	86	82	346
Annual average	292	70	280

[1] Calculated from chloride values.
[2] Average chloride, Dow Chemical Co. data, 1956.

FURTHER COMMENTS ON SUPPRESSION OF SOME NAMES IN THE FAMILY BELONIDAE (PISCES). Z.N.(S.) 1723

(see volume 22, pages 325–329 and volume 23, pages 149–154)

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The International Commission on Zoological Nomenclature has been asked to concern itself with the relative status of four pairs of names of four species of Belonidae, for which conflicting opinions exist. The Commission has been asked to officially accept or reject seven of these eight names.

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Bull. zool. Nomencl., Vol. 24, Part 4. September 1967.

Collette and Berry (1965, 1966) considered the proper names to be:

(1) *Platybelone argalus* (described as *Belona argala* LeSueur, 1821)

(2) *Strongylura marina* (described as *Esox marinus* Walbaum, 1792)

(3) *Tylosurus crocodilus* (described as *Belona crocodila* Peron and LeSueur, 1821)

(4) *Tylosurus acus* (described as *Sphyraena acus* Lacépède, 1803).

For the same four species, in the same respective order, Mees (1962, 1964, 1966) used the names:

(1) *Belone platyura* (described as *Belone platyura* Bennett, 1832),

(2) *Belone houttuyni* (described as *Esox houttuyni* Walbaum, 1792),

(3) *Belone marisrubri* (described as [*Esox belone*] Var. *Maris rubri* Bloch and Schneider, 1801),

(4) *Belone imperialis* (described as *Esox imperialis* Rafinesque-Schmaltz, 1810).

Collette and Berry (1966) petitioned the Commission to reject three names and substitute three others. Our opinion for rejection of two of the names was based on the fact that they were *nomina oblita*. Because Article 23b of the Code concerning *nomina oblita* has been or may be suspended, Collette rephrased the request concerning those two names (in a manuscript that I affirm).

When Mees resurrected and used the specific names *houttuyni* of Walbaum and *marisrubri* of Bloch and Schneider, he did so in specific contradiction of Article 23b of the Code, which stipulates: " (i) After 1960, a zoologist who discovers such a name is to refer it to the Commission . . .," and " (ii) A *nomen oblitum* is not to be used unless the Commission so directs."

Mees' action was also contrary to the intent of the Code—he stated (1966 : 149) that he based his opinion of the correct name of a species " on the principles of priority and clarity of description."

Collette and Berry's opinion as to which name to use for a species is based on the two principles: (1) priority and (2) *stability of nomenclature* (see Preamble to the Code, Articles 75(a), 78(b) (ii), and 79, and Recommendations 24A and 74A).

Type specimens apparently do not exist for any of the eight nominal species under discussion. If we follow Recommendation 75A of the Code, it would be difficult to resolve the issue at this time by defining the nominal species through the designation of neotypes. The only method remaining, therefore, for stabilization of these species' names is for the Commission to decide which names are valid.

If the Commission consider the relative status of a name on the basis of clarity of description, conflicting views might be presented *ad infinitum*. This point is illustrated by the following:

(1) After referring to his first, 96-page treatment of the Belonidae as a " Preliminary Revision," presented " in an incomplete form ", Mees published a 16-page paper (1964), in which he implied that there was little more to be done in comprehending the taxonomy of the Belonidae. Some of his statements were: " Though, inevitably a few problems remain to be solved . . . "; " The statement that systematically the Belonidae are a well-known group seems justified . . . "; " I believe therefore that the systematic list on p. 325 is almost complete and will undergo only minor changes in future." These quotations are taken out of context, but I feel that this does not change their basic meaning.

Contradictions to this view are apparent. For example, a recent publication by Collette (1966) described a new genus (*Belonion*) of appreciable phylogenetic significance, and two new species.

(2) Two scientists can interpret the same set of facts relating to genera and species in decidedly different ways. Mees recognized only two genera in the Belonidae—*Belone* and *Potamorrhaphis*—and stated (1964 : 312): " All other genera proposed are one-character genera . . . " This statement is obviously a faulty piece of scientific information, based on lack of investigation of the abundant characters of generic significance (according to current thought). On the basis of " clarity of description ", Mees' selection of proper species names lacks credence because he did not study enough characters in a sufficient number of specimens.

(3) After implying that almost everything about belonid taxonomy was settled, Mees (1966) presented a lengthy reply—over 3,000 words and 35 references—to the comments of Collette and Berry (1966). Both Collette and I (in press, and herewith) have now spent additional research time replying to *his* reply.

In any action that may be taken on these names, I urge the International Commission on Zoological Nomenclature:

(1) to reject the proposal to suppress *Belona argala* LeSueur, 1821—affirming *Belona platyura* Bennett, 1832 as its junior synonym—on the principle of priority;

(2) to accept *Esox marinus* Walbaum, 1792—suppressing *Esox houttuyni* Walbaum, 1792, or declining to act on its status—on the principle of stability of nomenclature;

(3) to accept *Belona crocodila* Peron and LeSueur, 1821—suppressing " [*Esox belone*] Var. *Maris rubri* " Bloch and Schneider, 1801—on the principle of stability of nomenclature;

(4) to accept *Sphyraena acus* Lacépède, 1803—rejecting *Esox imperialis* Rafinesque-Schmaltz, 1810 or denoting it as a junior synonym—on the principle of priority.

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Reprinted from
Proceedings of the
GULF AND CARIBBEAN FISHERIES INSTITUTE
Nineteenth Annual Session, November, 1966
116-128

Pompano: Biology Fisheries and Farming Potential[1]

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Abstract

The common pompano, one of the five species of *Trachinotus* of the east coast of the Americas, has for years comprised small but important fisheries in Florida.

Appreciable interest in the possibility of farming pompano has been generated in recent months, and farms have been started in central Florida that offer hope of success.

Unfortunately from the standpoint of farms, very little is known of the biology and ecology of the pompano. What little information is extant is summarized in this paper. Until research is conducted that will clarify many of the unknowns of the biology of the pompano, efforts at producing a profitable crop in ponds will be on a trial and error basis.

Research on the pompano's biology and farming potential is being inaugurated at the Virginia Key Marine Science complex at Miami. Results of this research will be made readily available, and we request that information on pompano from other areas be communicated to us.

INTRODUCTION

IN JUNE 1966 our laboratories at Miami began to receive inquiries about pond farming of pompano. Similar inquiries were directed to the U.S. Fish and Wildlife Service in Washington, D.C. and the Florida State Board of Conservation. This interest was generated in part by recent publicity about a pompano farm in St. Augustine, Florida.

The trial raising of pompano in commercial quantities and in a controlled environment offers one way of improving knowledge for increased use of the protein potential of the sea. Techniques developed in studies of pompano raising should be applicable to the controlled production of many other marine animals. Furthermore, the product would find a ready commercial market. Pompano is one of the most highly desired marine fishes; its flavor is excellent and its monetary value is high. The commercial catches are not large and are often unpredictable.

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[1] Contribution No. 51 — Tropical Atlantic Biological Laboratory, Bureau of Commercial Fisheries, Miami, Florida 33149.
Contribution No. 814 — Institute of Marine Sciences, University of Miami, Miami, Florida 33149.

In attempting to answer the inquiries about pompano farming, we began to collect information on the biology of pompano (which we knew was limited) and on the feasibility of pursuing additional research needed for successful farming.

Several trials at pompano farming have been made, but these have had little success. The trials have been too few, and the basic knowledge of the biology of the pompano is too meager. We consider the prospects promising and propose that the necessary research be pursued.

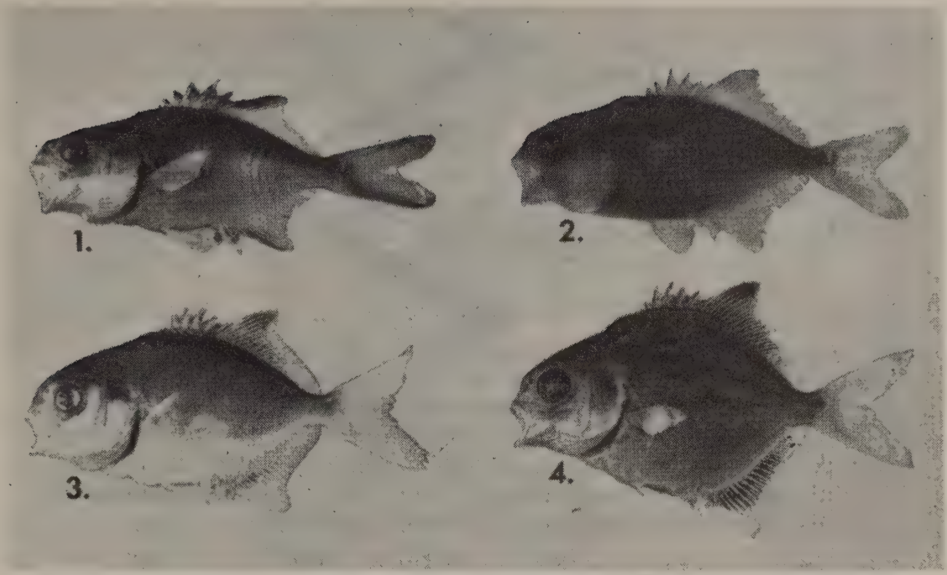
Interest in fish farming has been longstanding. Many persons along the eastern seaboard of the United States have considered raising lobsters, shrimp, and a variety of marine fishes. A few farms were started, but their success was small.

Current opinion among economists concerned with food for the human population is that much of the protein needed by future generations will come from the ocean. Many who promote this thought are not aware that the basic knowledge of the biology of most marine animals and plants is fragmentary, often nonexistent; and that their views are based on little more than wishful speculation. Successful procedures for culturing most marine organisms have yet to be developed. Development of techniques will depend largely on adequate knowledge of the biology of the organisms concerned and their tolerances and needs.

TAXONOMY

Several species of fishes in various parts of the world have the common name pompano. We restrict this name to species of the genus *Trachinotus* of the family Carangidae. Five species live in marine waters of the eastern coasts of the Americas and in the West Indies, but only three of them occur along the coast of the United States:

1) *Trachinotus marginatus,* the pampano, of Argentina and Brazil.
2) *Trachinotus cayennensis,* the pompano zapatero of Venezuela to Brazil.
3) *Trachinotus goodei,* the palometa, also known as the longfin pompano (previously designated by the scientific name of *Trachinotus glaucus)* (Fig. 1). It ranges from Massachusetts to Argentina and occurs at Bermuda. It grows to a total length of at least 13 inches.
4) *Trachinotus falcatus,* the Atlantic permit, also called the great pompano and (when young) the round pompano (Figs. 3 and 4). This species ranges from Massachusetts to Brazil, and grows to a weight of about 50 pounds and a total length of about 3 feet.
5) *Trachinotus carolinus,* the pompano, also named common pompano, or Atlantic pompano, sometimes called sunfish, (Fig. 2). This most common and desired species ranges from Massachusetts to Brazil. The maximum total length and weight are uncertain, because smaller Atlantic permit have been confused with this species.



Figs. 1-4. Young of the three species of pompanos occurring on the Gulf and Atlantic coasts of the United States. (The measurements given are total lengths.) Fig. 1. Palometa *(Trachinotus goodei)*, 2 inches. Fig. 2. Pompano *(T. carolinus)* 2-1/8 inches. Fig. 3. Permit *(T. falcatus)*, shallow-bodied, 1-7/8 inches. Fig. 4. Permit, deep-bodied, 1-7/8 inches.

IDENTIFICATION

Softrays

The number of softrays in the dorsal and anal fin can be used to separate the pompano from the permit and the palometa:

	Dorsal Softrays	Anal Softrays
pompano	24-25	21-22
permit and palometa	17-21	16-19

Counts of 90% of the pompano examined are within these ranges, but higher and lower counts do occur (dorsal 22-26, anal 20-23). The distinction between spines and softrays in the dorsal and anal fins is shown in Fig. 5. With experience, larger specimens of permit and palometa can be distinguished from those of pompano by the relative spacing of the softrays, especially in the anal fin.

Body Depth

For specimens about 1 to 4 inches long the depth of the body (from the 7th dorsal to 1st anal spine) separates the permit from the pompano and the palometa: palometa (Fig. 1) and pompano (Fig. 2) — body depth 2 1/3 times or more in standard length; permit (Figs. 3 and 4) — body depth 2 1/4 times or less in standard length.

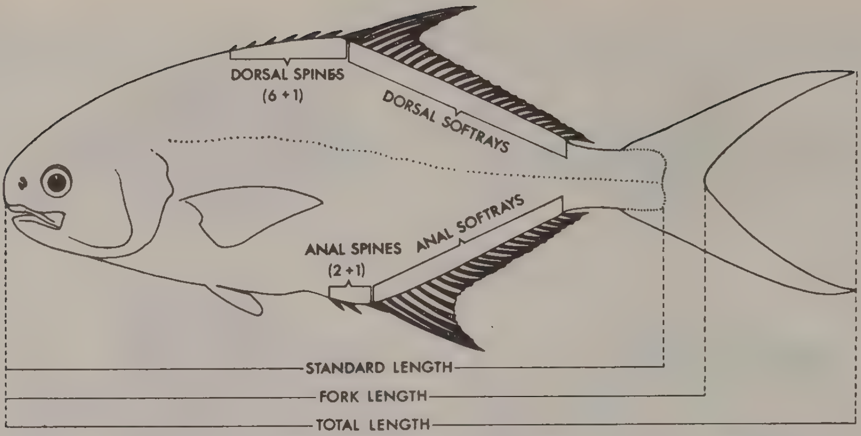


Fig. 5. Diagram of a young pompano showing the three lengths commonly used, (standard, fork, and total) and the distinction of spines and softrays in the dorsal and anal fins.

Color of Anal Fin Lobe

Recently caught fry or small juveniles can be distinguished by the color of the lobe of the anal fin: pompano: yellow or lemon yellow, shading in some to cinnamon near tip of lobe; permit: bright orange, or red, almost black in dark-bodied individuals; palometa: clear, black on anterior edge.

Lengths

The three lengths most commonly used in measuring fishes are diagrammed in Fig. 5. For small pompano, the approximate factors to convert from one length to another are (Standard Length, SL; Fork Length, FL; Total Length, TL):

SL = TL x 0.76
SL = FL x 0.88
FL = SL x 1.13
FL = TL x 0.88
TL = SL x 1.32
TL = FL x 1.14

These factors apply best to pompano of 4 inches or less total length. For example, a factor of 1.40 is a better approximation than 1.32 for converting standard length to total length in larger palometa.

POMPANO BIOLOGY

No comprehensive research has been conducted on the biology of the pompanos. The most significant account of young pompano is by Fields (1962) but its coverage is limited. The following observations are from the available literature and from personal communications and observations.

Food

In nature, young pompano feed primarily on benthic and pelagic invertebrates, such as amphipods, bivalve mollusks, crab larvae, copepods, and isopods; at times they feed heavily on the young of other fishes, particularly clupeids. The adults appear to have similar food preferences. In captivity, the young grow well on a diet of mixed ground shrimp, fish, and frozen brine shrimp. Fish meal may be an adequate diet. Larger fish thrive on ground or chopped fish; they have also been fed ground scrap fish from trawl catches, chicken feed, and tankage from slaughter houses.

Growth Rate

Young pompano in nature probably grow about 1/2 to 1 1/4 inches per month (average slightly less than 1 inch per month). Fish in captivity have been raised from a length of about 1 inch to over 10 inches and a weight of about 1 pound within about one year.

Longevity

The life span of the pompano is unknown, but our guess is that under natural conditions it is 3 or 4 years.

Spawning

We speculate that most, if not all, spawning is in offshore oceanic waters, because the smallest pompano larvae so far identified have been taken offshore. We have no available accounts of the capture of running-ripe pompano, although we have heard reports of pompano from inshore waters containing enlarged ovaries with macroscopic eggs. It is possible that eggs of these fishes were not fully ripe. Spawning off the southeastern United States may begin as early as February and continue through August or September. A northward seasonal progression of spawning probably occurs, although spawning may occur throughout the year in the tropical Gulf of Mexico and the Caribbean Sea.

Movements and Migration

At least part of the population of pompano appears to move northward along the southeastern United States in the spring and summer. The young and adults appear off the New England States, usually from July to September or October. Presumabily they return southward and nearer to warmer, offshore waters during the colder months.

Fry of the pompano are rare in our collections in the Miami area, but young of the permit and palometa are abundant. Pompano fry are the most abundant of the three species on the beaches of Georgia and northeast Florida.

Limited numbers of pompano have been tagged in Florida waters by the Florida State Board of Conservation (Topp, 1963; Beaumariage, 1964; Beaumariage and Wittich, 1966). Of 45 pompano reported tagged during 1962-1964; 3 were recaptured. One was taken near the location of tagging 25 days later, the second was taken 43 miles north of the tagging site 4 days after release, and the third was taken 164 miles south 284 days later. One palometa tagged at Fernandina, Florida, on July 19, 1965, was recaptured 65 days later in North Carolina. Two palometa tagged at Matansas Inlet, Florida, on July 7 and 8, 1965, were captured 78 and 10 days later at Jensen Beach and Miami Beach, Florida.

Environmental Tolerances

We have no information on tolerance to high temperatures, but temperatures as low as 50-60F have produced partial or complete kills in captive stocks, and 40F usually is fatal. Pompano less than 6 months old may be more tolerant of extremes of physical and chemical changes than older fish. Mortality in captive stocks has been attributed to low oxygen concentrations, especially in combination with high temperatures. Space can be a limiting factor in captive conditions, and fish maintained in relatively static small aquaria (even up to 500 gallons) have ceased to grow above a size of about 3 or 4 inches. Overcrowding might limit growth in an impoundment that has limited water exchange.

COMMERCIAL FISHERY

Commercial landings of pompano are made in all coastal states from Virginia to Texas, but about 90-95% of the total United States catches are landed in Florida. In 1965 about 833,000 pounds of the total U.S. landings of about 886,000 pounds were taken in Florida (Bureau of Commercial Fisheries Branch of Statistics). In Florida landings of marine food fishes in 1965, pompano made up more than 1% of the total weight and more than 5% of the total dollar value, and about 0.4% of the weight and about 1.6% of the value of the total Florida commercial catch of fish and shellfish. Values are based on ex-vessel prices, which are high in themselves (currently about $0.65 per pound). Prices may be twice as high when the pompano reach the retail market. Estimates by Bureau of Commercial Fisheries personnel indicate that if the ex-vessel price averages $0.65 per pound, the wholesale price might average $0.90, and the retail price $1.40 (with a usual retail price range of $1.10 to $1.85). This mark-up has considerable importance for fish farming because the farmer can sell directly to restaurants and retailers, taking advantage of the higher price.

Catches in Florida increased from about 400,000 pounds in 1955 to nearly 833,000 pounds in 1965 (Fig. 6). The price per pound was high in 1955-57, dropped in 1958, increased until 1962, and then dropped again. The high price of about $0.80 to $0.90 per pound in 1955-57 was probably due to considerable sales promotion of this species by governmental agencies. Most pompano are caught on the west coast of Florida from Monroe County including the Florida Keys, to Charlotte County at Fort Myers (Fig. 7, West Florida — Southern). The greatest catches on the east coast are made from Brevard County at Cape Kennedy south to Palm Beach County (Fig. 7, East Florida — South Central). Most of the pompano caught in Florida are from outside waters, although some are from the Indian and Banana Rivers near Cape Kennedy. Most pompano are taken in large trammel nets but a small proportion are taken by gill nets. Various types of nets or seines account for the remainder.

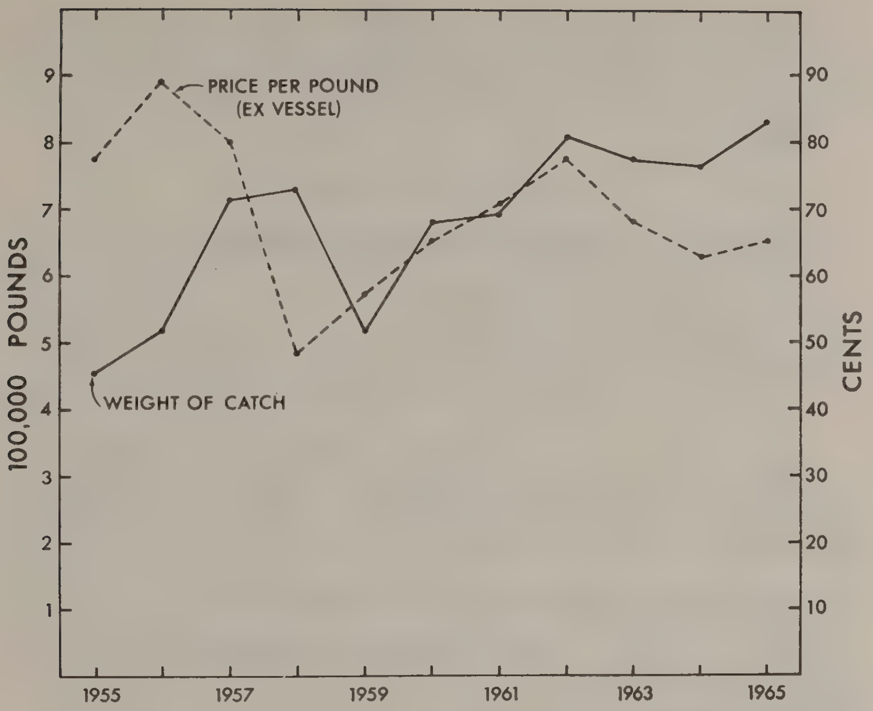


Fig. 6. Commercial landings of pompano in Florida, 1955-65, showing weight of catch and ex-vessel price per pound.

In the Florida Keys, airplane spotters' occasional assistance to fishermen in locating pompano has helped to increase the catches in recent years.

The seasonal trend in pompano landings on the west coast of Florida shows highest production during the winter (Fig. 7). The same trend is apparent on the east coast, but is not as striking. The greatest production of pompano from the inside waters of the Indian and Banana Rivers at Cape Kennedy was during May-September (Anderson and Gehringer, 1965). Of eight dominant species studied in the Cape Kennedy area, three (black mullet, blue crab, and pompano) are taken exclusively in inside waters. Pompano leave the relatively shallow waters during the winter and move offshore. This movement accounts for the difference in the trend in this fishery and the total fishery on the Florida east coast.

SPORT FISHERY

As with commercial fishing, sport fishing for pompano is relatively limited in comparison with many other species of marine fishes. Pompano, however, is a popular surf gamefish, and interest in sport fishing is increasing. They are good fighters when hooked on light tackle and are a highly prized food fish. Some fishermen pay for their trip by selling part of their excess catch to restaurants or retail fish markets. Fishermen catch

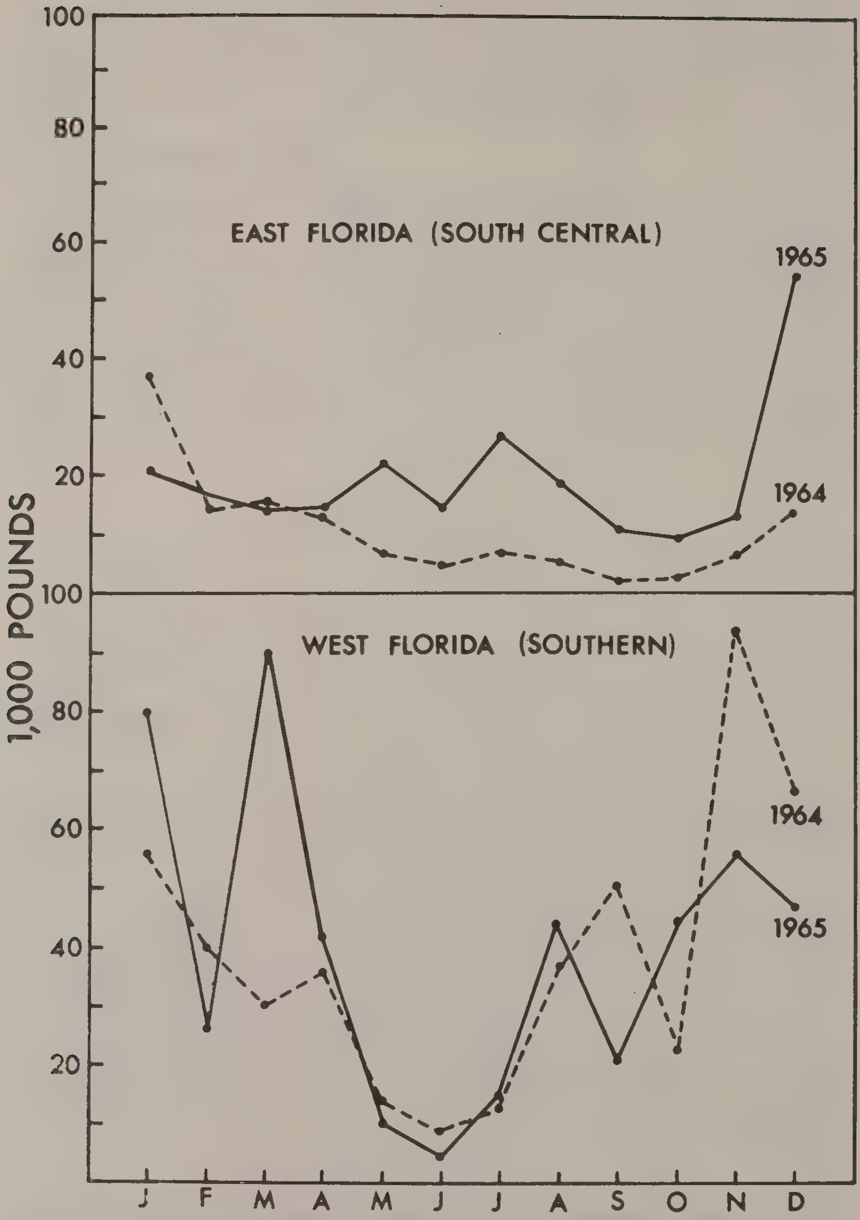


Fig. 7. Commercial landings of pompano, by month for 1964 and 1965, from the South-Central Florida East coast and the Southern Florida West coast.

pompano by bottom fishing offshore or by casting from boats or shore. The most ardent pompano fishermen often prefer to walk or ride along the ocean beaches and to cast in front of a school, using sand fleas for bait. A good account of pompano angling was given by E. C. Buckout *in* McClane (1965: 693-694).

POMPANO FARMING

Fresh-water fish farming for trout, catfish, bait species, and goldfish is successful in the United States, but few marine and brackish water species are raised. In many tropical countries fish are raised either as a profitable farming operation (milkfish, mullet, and *Tilapia*) or at the subsistence level of the people. In the temperate and subtropical waters of the world fewer fish are raised, although milkfish and mullet support large industries in some areas (especially in the Philippines, France, and Italy).

Pompano seems to be a suitable fish for farming, partly because of the current high price paid to fishermen. This price undoubtedly could be raised by promotion. In addition, the demand for pompano is high and apparently can be increased, especially with a predictable supply.

From a biological standpoint the pompano seems to be highly suitable for farming, but in this respect our information is meager. Pompano apparently grow rapidly, even in confinement. They can be fed on "trash fish" or fish that are discarded by shrimpers. Since cannibalism is unusual, different sizes can be placed in the same pounds.

The diseases of pompano have not been carefully investigated, but the presence of parasitic protozoans, roundworms, tapeworms, and flatworms has been reported (Linton, 1905, 1940). Sporozoan parasites that are present on the fins could, under conditions of impoundment, cause epidemics (epizootics). We must learn a great deal more about the diseases of pompano.

One disadvantage of pompano farming is that the stock for farms at present must be collected along sandy ocean beaches (Fig. 8), as young milkfish must be caught to supply farms in the Philippines. Pompano have been reported to spawn in ponds, but these reports are unauthenticated and doubtful.

The Beginnings of Pompano Farming in Florida

At least two attempts have recently been made at raising pompano in the Florida Keys. Pompano farming would seem to offer a better chance of success in this area than in more northern areas of the State, where freezing temperatures have frustrated other attempts. Other pompano farms recently started in Florida include one at Pensacola Beach (stocked in the spring of 1966) and operations at West Palm Beach and Bradenton.

Attempts at raising pompano fry in 1/2-acre ponds near St. Augustine were started between 1957 and 1962. Small pompano fry

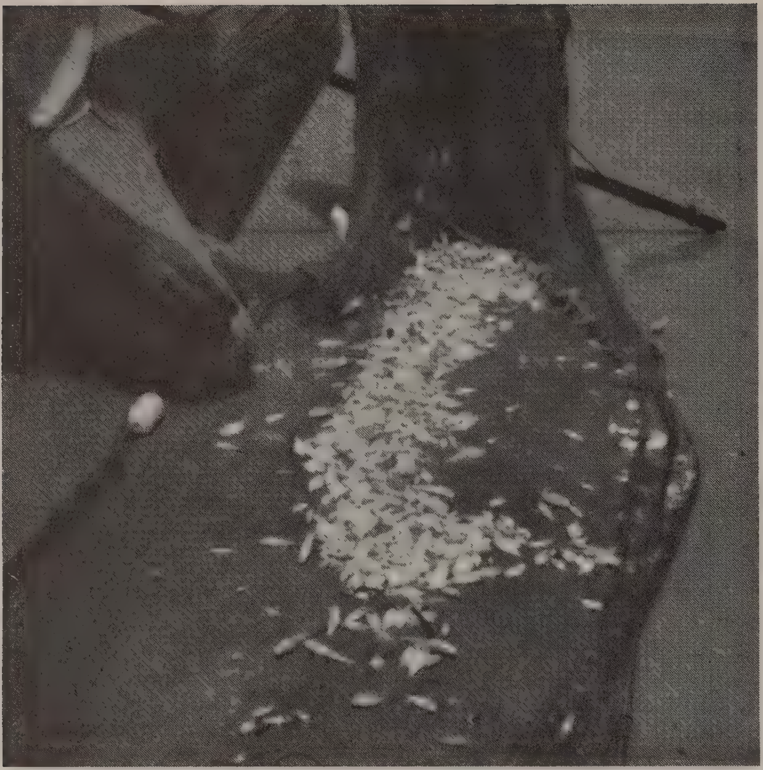


Fig. 8. Catch of young pompano from surf zone near St. Augustine pompano farm.

caught with seines on the open beach were placed in the ponds. In three of the early years (1957, 1959, and 1960) the young pompano were carried through the fall, but were killed by low temperatures. In 1958, all young pompano in a 1/8-acre pond were killed after a dam between the small pond and an adjoining larger pond containing an artesian well broke and flooded the smaller pond with fresh water. Another trial in this area failed when a dike separating a small pond from the Indian River breached and all the stock escaped.

In June 1960, the 1/8-acre pond near St. Augustine was stocked with about 2,500 pompano (all *Trachinotus carolinus*) about 3/4 to 1 inch long. They were fed six times daily, and grew to a length of about 7-8 inches in May 1961. Then a sudden, complete mortality occurred, which was attributed to oxygen depletion. A pipe allowing water exchange on high tide had become clogged by invertebrates (tunicates). The kill took place on a hot day with a small tidal fluctuation. This pond was restocked in June 1961 with an estimated 1,500 pompano about 1 inch long. In September 1962, about 700 of these fish, weighing about 1.1 pounds each, were marketed at $1.25 per pound. The fish were reported

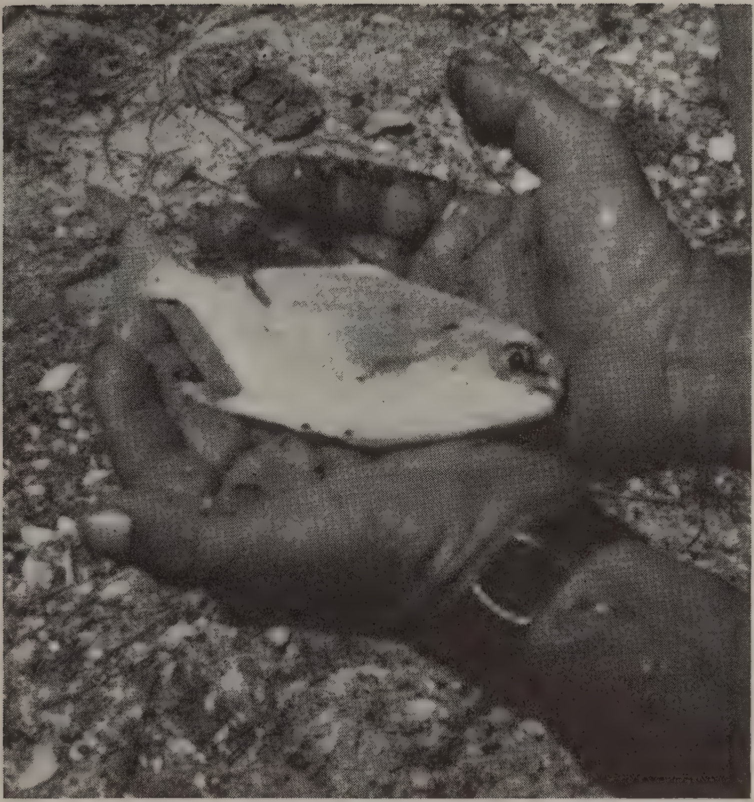


Fig. 9. Seven-month old pompano raised at St. Augustine farm.

to be choice, plump, and in good condition. Attempts to raise pompano in this pond were terminated in 1962, after the pond had been restocked and another die-off had occurred.

A pond was constructed in 1963 at Matansas, a short distance south of St. Augustine, and stocked with pompano fry in the spring of 1964; a hurricane in September 1964 broke the dike and all fish were lost. In 1965 two ponds, 1/8 acre and 3 acres in area, were constructed at Matansas, and were stocked with fry in June and August, 1965. Two extensive mortalities occurred in the larger pond, but the fish in the smaller pond lasted through the winter and were put into the larger pond early in 1966. The larger pond was also restocked with fry in May 1966. Several thousand pompano in this pond are now reported to be at or near a marketable size (Fig. 9).

Results of experimental pompano raising at Marineland near St. Augustine were reported by Fielding (1966). Ponds were stocked with small pompano (weighing about 1/70 to 1/3 ounce) at rates of 3,200 to 12,200 fish per acre. The experiments were terminated between 65 and 133 days later with production ranging from about 1,500 to 2,400 pounds per acre. The fish averaged about 10 inches total length and 0.6 pound.

Preliminary Recommendations on Pompano Farming

In view of the limited knowledge of the biological requirements and tolerances of the pompano, the following recommendations must be tentative:

1) After the fry are netted on the beach, they should be moved carefully and rapidly to a carrying tank, and transferred as quickly as possible to their first growing pond or aquarium. Use of compressed oxygen or air may be needed to transport the fry long distances.

2) Only one species of *Trachinotus* should be stocked; by popular preference it should be the common pompano, *Trachinotus carolinus*.

3) Larvae and fry of other fishes and invertebrates that could compete with the pompano for food and space should be excluded from the pond if possible.

4) The young pompano should be fed several times each day. We have been told that the very young may require a daily ration of about 1/10 of their body weight.

5) A finely ground food of frozen adult brine shrimp, fish filets, and whole shrimp has proved satisfactory for young pompano in the first 2 months or so after capture. Ground shrimp heads and ground or cut whole scrap fish are good when the pompanos are 3 to 4 inches long and larger. Fish meal suffices for fish of all sizes, but small pellets of fish meal are more economical for larger fish.

6) Newly-caught fry should be placed in an aquarium or small pond for a few days or weeks for observation of food requirements. More efficient use of the food offered and the culling of sickly or diseased fish and of other fish species can be accomplished.

7) Young pompano should not be retained too long in aquaria or small ponds, because it has been demonstrated that growth of fish often slows when they are crowded.

8) Pompano probably grow better at a nearly constant temperature. Extremes of temperature, especially below about 50F are usually injurious or fatal.

Among the problems that need to be investigated are the following:

1) Optimum salinity and temperature for holding pompano.

2) Diseases of pompano which could affect production.

3) Amounts and kinds of food which should be fed to pompano of various sizes.

4) Optimum sizes of ponds and stocking rates.

5) Important biological factors such as growth rates and life span.

Anyone considering pompano farming should consult the Conservation Department in his state to determine if there are closed seasons, minimum size limits, or other restrictions on the capture, confinement, and sale of pompano.

Considerable information is necessary before pompano farming can be on a secure, profitable basis. Farmers can begin without this information, but their operations at present must be trial and error. A guarantee of investment can be assured only after research and controlled experiments have provided needed information on the biology of pompano and the practicality of farming them. The promise of success for farming this species is great enough to justify the needed research.

ACKNOWLEDGEMENTS

We thank the many individuals who have given us information and assisted in preparation of this account, especially the following: Burton Clark and Warren Zeiller, Miami Seaquarium; Jack W. Gehringer, U.S. Bureau of Commercial Fisheries, Brunswick, Ga.; Clarence Idyll, Institute of Marine Science, University of Miami; Robert M. Ingle and Martin A. Moe, Florida State Board of Conservation, St. Petersburg; Lloyd E. Johnson and Grady W. Reinert, U.S. Bureau of Commercial Fisheries, Miami; Robert F. Johnson, U.S. Bureau of Commercial Fisheries, Gulf Breeze, Fla.; Cliff Townsend, Marineland Studios, Fla.

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Made in United States of America
Reprinted from COPEIA, 1967, No. 1, March 20
pp. 46–50

Macristiella perlucens, A New Clupeiform Fish from the Gulf of Mexico

FREDERICK H. BERRY AND C. RICHARD ROBINS

Macristiella perlucens, A New Clupeiform Fish from the Gulf of Mexico[1]

FREDERICK H. BERRY AND C. RICHARD ROBINS

***Macristiella perlucens*, a new genus and species of fish, is described from a small specimen taken in the western Gulf of Mexico. It is related to *Macristium chavesi* Regan of the previously monotypic family Macristiidae. The relationships of this family are discussed and it is placed in a new suborder, Macristoidei, of the order Clupeiformes (*sensu lato*).**

A unique 1½-inch long fish swimming at the surface under a night light was dipnetted by Harvey R. Bullis, Jr. from the R/V OREGON in 1954, about 50 miles NE of Tampico, Mexico in the Gulf of Mexico.

The generally transparent fish remained alive for about 20 min in a dish of seawater, and was photographed with 35 mm Kodachrome film under camera lights. It became opaque within about 3 min after death, was photographed again, and placed in 10% formalin (H. R. Bullis, pers. comm.). It was later drawn in lateral view, cleared with potassium hydroxide, stained with alizarin, and preserved in glycerine. Certain structures were illustrated from the cleared and stained specimen, and the illustrations and the specimen were examined by a number of ichthyologists.

It was not until April of 1964 that we were able to determine the taxonomic position of this unique form. Comparison of the specimen from OREGON station 1072 with *Macristium chavesi* Regan (1903, 1911), as redescribed by Marshall (1961), showed that the OREGON specimen is undescribed and that it represents the second known species of the family Macristiidae, which we include in the order Clupeiformes. It differs sufficiently from *M. chavesi* to merit placement in a separate genus, diagnosed below.

Macristiella, new genus

Diagnosis.—Maxillae toothless. Supramaxillae absent. Adipose fin present. Pseudobranchia present. Nasal openings separate, remote. Posttemporal bone simple, not bifurcate. Five branchiostegals in series attached to external face of the hyal apparatus, the remaining branchiostegals attached to the ventral edge. Principal caudal rays 10 + 9. Vent well in advance of anal-fin origin. Dorsal fin short-based, its origin above posterior end of pelvic-fin base and well in advance of anal-fin base.

Name.—*Macristiella*, diminutive of *Macristium*, to be treated as feminine.

Type-species.—*Macristiella perlucens*, new species. Monotypic.

Macristiella perlucens, n. sp.

Figs. 1–4, Table 1

Diagnosis.—(Characters are in addition to those listed in diagnosis of genus.) Branchiostegal rays 5 + 11. Dorsal-fin rays 12. Gill-rakers 8 + 17. Myomeres 69. Dorsal and anal fins moderately rounded, anterior rays not extremely produced.

Description.—Body elongate, tapering posteriorly. Abdomen rounded and protruded. Dorsal profile of head slightly convex in Kodachrome slides of the freshly caught specimen (portrayed in the drawing made in 1962 with the specimen preserved in formalin). In the cleared and stained specimen, the supraoccipital appearing to protrude into the dorsal profile with slight convexities in the profile anterior and posterior to the eye. This similar to the profile depicted for the two specimens of *M. chavesi* (Marshall, 1961, Figs. 1, 4a), and probably representing shrinkage of soft parts in these three specimens.

Premaxillae without prominent ascending processes and with 11 teeth on the right side and 10 teeth on the left (Fig. 3). Maxillae entering the posterior half of the gape and toothless. No supramaxillae. Lower jaw with two large teeth on each side at the symphysis and six smaller teeth on the right side and eight on the left. Tongue bearing one median tooth and two lateral teeth on each side in a transverse row. Head of vomer slightly ossified with four teeth on

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[1] Contribution No. 46 from the Tropical Atlantic Biological Laboratory, U. S. Bureau of Commercial Fisheries, Miami. Contribution No. 765 from the Institute of Marine Science, University of Miami.

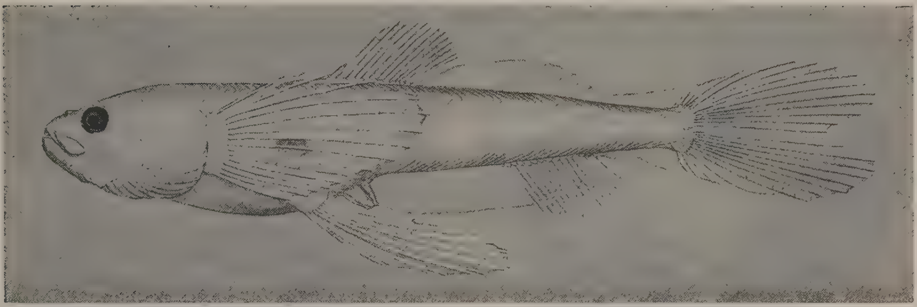

Fig. 1. *Macristiella perlucens*, holotype, 28.5 mm SL, USNM 201051. Drawn from the formalin-preserved specimen.

each side in a transverse row. Posterior four-fifths of each palatine ossified, with a single tooth anteriorly on the unossified portion.

Dorsal fin with 12 rays, the last ray branched to its base; no other dorsal rays branched, but the tips of many rays fimbriated; all rays with one or more segment marks. The fin margin slightly rounded, with no excessively shortened or elongated rays. Fin base over about the 17th to 28th myomeres; the fin origin dorsal to the termination of the base of the pelvic fin. Anal fin with 13 rays; branching, segmentation, and shape of fin like that of dorsal fin. Fin base extending between about the 43rd and 53rd myomeres. Pectoral fins with 15 rays each, the fin insertion placed vertically and centrally on the side of the body, the margin rounded with the 5th ray the longest; the rays segmented but unbranched. Each pelvic fin with 8 rays, the rays segmented, and the median 6 rays branched. Caudal fin with 10 superior and 9 inferior rays and with 6 dorsal and 4 ventral secondary rays; most of the principal rays segmented, but none appearing to be branched. The fin forked with the lobes subequal and rounded. Caudal-fin bones (Fig. 4) not ossified and appearing to be in a larval stage. Segments of the urostyle not separated, and the tip of the urostyle continuing to the body margin. Four superior (dorsal) and three inferior (ventral) hypurals. The posterior two haemal spines entering into the caudal complex. Epurals, uroneurals, and posterior neural spines not discernible, but three opaque structures present on the damaged specimen possibly representing epurals.

A dorsal finfold extending from the termination of the dorsal-fin base onto the caudal fin; within this finfold an area, above the 42nd to the 51st myomeres, with a fimbriated margin defined by us to represent an incipient adipose fin. A short, postanal finfold extending from near the end of the anal fin onto the caudal fin. A preanal finfold extending over the space of about 19 myomeres, connecting the protruding gut with the anal fin.

Each pseudobranchium with two filaments.

Nasal openings paired and separated each side, slightly elongate, and aligned anteroposteriorly.

Scales absent.

When first seen by us (1958), the specimen had only two areas pigmented, the eyes and an internal medial area in the roof of the visceral cavity. This visceral area of pigment has since faded, but it was reminescent of the bilateral visceral pigment patches of larval and juvenile paralepidids and synodontids. Kodachrome slides, taken while the fish was fresh, show a whitish, transparent body background with prominent and elongated bluish or violet spots on the interradial membranes of the pectoral fins (about 30) and pelvic fins (about 14). Less distinct bluish spots appear in lines on the caudal fin, but this area is not shown distinctly. The slides show a deep violet patch in the visceral region and lighter violet or blue areas extending onto the head, and a trace of blue on the snout. The pupil is black, the iris is silvery and is rimmed dorsally by a black lens ("eyeshade") over the supraoccipital.

Material.—Holotype: USNM 201051, a juvenile, 28.5 mm in standard length, at surface over water 600 fm deep, at lat. 22°43′ N, long. 97°10′ W, about 50 miles NE of Tampico, Mexico, R/V Oregon station 1072,

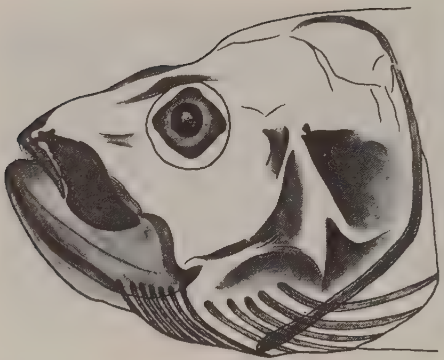

Fig. 2. Lateral sketch of head of *Macristiella perlucens*, drawn after clearing and staining.

at night, 24 May 1954. The Kodachcrome slides of the fish specimen are also deposited at the U. S. National Museum.

Name.—From the Latin, *perlucens*, a present participle used as a masculine substantive of the third declension, meaning one who shines through, in allusion to the transparent nature of the species.

Discussion

Macristiella is most closely related to *Macristium*, whose single species *M. chavesi* Regan is known from two small specimens from the eastern Atlantic Ocean (Azores and Bay of Biscay). These specimens were described in detail by Marshall (1961:356–363). *Macristiella* differs from *Macristium* in seven of the characters listed in Table 1, of which the higher branchiostegal count seems most important. Although the *Macristiella* is the smallest of the three (standard length 28.5 *vs.* 33 and 110 mm), it seems to represent developmentally a stage between the other two. In some features, such as the composition of the branchiostegal rays and the caudal structure, no information is available for *Macristium*. The dental patterns of *Macristium* and *Macristiella* are similar, and the simplicity and placement of the posttemporal bones are much the same. Both lack a swimbladder. *Macristiella* has two openings to the olfactory organ, as does the larger specimen of *Macristium chavesi*.

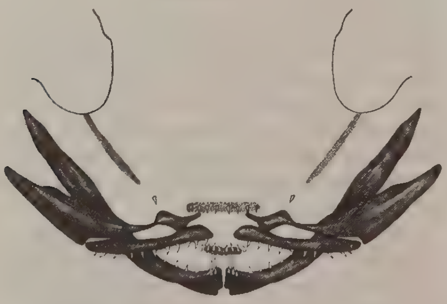

Fig. 3. Dorsal view of jaws and teeth of *Macristiella perlucens*.

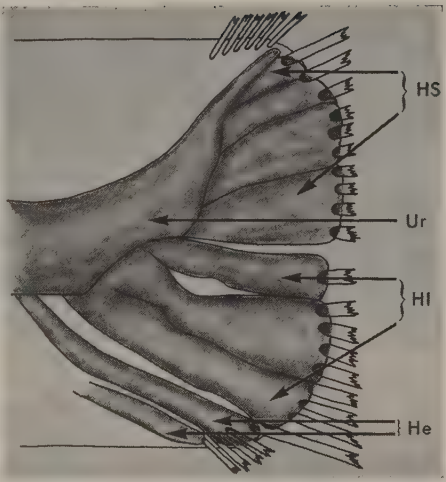

Fig. 4. Lateral view of caudal-fin structure of *Macristiella perlucens*. He, haemal spines. HI, inferior hypurals. HS, superior hypurals. Ur, urostyle.

Although the relations of *Macristiella* and *Macristium* seem clear enough, the placement of the family Macristiidae has posed problems. Marshall (1961:363–370) related *Macristium* to the Cretaceous genus *Ctenothrissa*, family Ctenothrissidae (Isospondyli). Patterson (1964:218–262) discussed ctenothrissid and aulolepid fishes in detail, placing them in the new order Ctenothrissiformes. On page 243 Patterson treated *Macristium* and removed it from that order. Greenwood *et al.* (1966:369–370) agreed with Patterson that the Ctenothrissiformes are more advanced than Marshall had supposed and placed them (Greenwood *et al.*, 1966:395 and Fig. 1) high in their Protacanthopterygii. They continued, however, to place the Macristiidae in the order Ctenothrissiformes.

The specimen of *Macristiella*, like those of *M. chavesi*, is a young fish and therefore

TABLE 1. COMPARISON OF COUNTS OF THE THREE KNOWN SPECIMENS OF MACRISTIIDAE.

	Macristium chavesi		*Macristiella perlucens*
	Holotype	DISCOVERY Specimen	Holotype
Dorsal rays	18	17	12
Anal rays	12	13	13
Pectoral rays	16	14 or 15	15
Pelvic rays	8	8	8
Caudal principal rays	10 + 9	10 + 9	10 + 9
Caudal secondary rays			6 + 4
Branchiostegal rays	ca. 8	10	16 (5, 11)
Gillrakers		3 + 14	7 and 8 + 1 + 16
Myomeres	ca. 62	61	69
Maxilla		toothed	not toothed
Pelvic-fin rays	simple	simple	branched
Last dorsal- and anal-fin ray	simple	simple	branched

the nature or presence of certain important structures can not be determined. However, there is no evidence of a supramaxilla, nor does the upper jaw resemble closely that of *Ctenothrissa radians* (see Patterson, 1964: 232, Fig. 9). The dentition of *Macristiella* is in single rows, totally unlike that of *Ctenothrissa*, and its maxilla is edentate. The posttemporals are bifurcate in *Ctenothrissa*, instead of being simple; and they articulate with the epiotic in *Ctenothrissa*, whereas they are contiguous with each other at the supraoccipital in *Macristiella*. Certainly, there is no epiotic process to receive the posttemporal in *Macristiella*. According to Patterson (1964:236), Woodward described four branchiostegals in the area under the subopercle in *Ctenothrissa*. *Macristiella* has five in this series which attach to the external face of the hyal apparatus. In this feature the ctenothrissids seem more advanced than *Macristiella*, as is in fact indicated in the dendrogram of suggested relationships by Patterson (1964:472, Fig. 103).

We follow Patterson, who removed the Macristiidae from the Ctenothrissiformes, but we do agree with Marshall (1961) that the Macristiidae belong to the order Clupeiformes in the broad sense of Berg (1940) and Gosline (1960).

Macristiidae is placed in a new suborder, **Macristioidei**, characterized by the lack of supramaxillae, the presence of a pseudobranch, in having five of the branchiostegals attached to the outer surface of the hyal apparatus (not known for *M. chavesi*), in having 10 + 9 caudal rays, and in having the pelvic fins nearly under the pectoral fins. Information is not available for many characters that would be vital to any detailed consideration of the relations of the suborder within the Clupeiformes. By example, we find no evidence of intermuscular bones in the Macristiidae, but ossification is not far advanced in any of the three specimens. This placement in a distinct suborder is based largely on gross dissimilarity to other groupings of clupeiform fishes and for convenience.

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Bureau of Commercial Fisheries Tropical Atlantic Biological Laboratory, and the Institute of Marine Science, University of Miami, Florida 33149.

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pp. 466–467

THE GOBY NAME *MICROGOBIUS CINCTUS* NICHOLS, A JUNIOR SYNONYM OF *LYTHRYPNUS DALLI* (GILBERT).—While engaged in a review of the genus *Microgobius,* I examined the types of *Microgobius cinctus* Nichols, 1952 at the American Museum of Natural History. *M. cinctus* is known from the holotype (AMNH 18725, a male 22 mm SL) and one paratype (AMNH 20935, 19 mm), both taken 3 April 1911 at Carmen Island, Gulf of California, by the Albatross Lower California Expedition.

It was apparent that *M. cinctus* was not a *Microgobius* but a species of *Lythrypnus.*

The type specimen of *Microgobius cinctus* has D VI, 17; A 12; P_1 18. The paratype has D VI, 16; A?; P_1 17. Nichols (*op. cit.*) erroneously gave the number of dorsal spines as seven for the paratype.

Lythrypnus dalli was described by Gilbert (1891:73) from a mixed syntypic series. Ginsburg (1939:53) restricted the name *Lythrypnus dalli* by designation of a lectotype (USNM 107287, 14 mm, Gulf of California, ALBATROSS station 3001, 24°55′15″ N, 110° 39′ W, 33 fm, 16 March 1889). The lectotype has D VI, 16; A 13; P_1 18. One of the paralectotypes (USNM 48255, 17 mm) has D VI, 18; A 14; P_1 18. Two other paralectotypes (USNM 126749), bearing the same data as the type, are in too poor condition to count.

The pigmentation pattern of the type of *M. cinctus* appears to be identical with that of the lectotype of *L. dalli.* Ginsburg (1939: 54) stated that color differences in the genus *Lythrypnus* are so constant that they are as important in distinguishing species as structural differences are in other genera.

Microgobius cinctus Nichols is similar in color pattern, fin formula, and other morphological characters to *Lythrypnus dalli* (Gilbert) and it is regarded as a junior synonym of *L. dalli.*

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MONTACUTA FLORIDANA COMMENSAL WITH ANNELID ONUPHIS MAGNA. — A number of bivalve mollusks of the eulamellibranch superfamily Erycinacea have been found in symbiotic association with annelids. Boss (1965, Malacologia, *3:* 183-195) has reviewed these occurrences. Along the Atlantic coast of North America, Stimpson (1855, Proc. Boston Soc. Nat. Hist., *5:* 110-117) first described *Lepton* [*Ceratobornia*] *longipes* as occurring in the "holes of marine worms and fossorial crustaceans." More recently Sanders *et al.* (1962, Limn. and Oceanogr., *7:* 63-79) found *Aligena elevata* (Stimpson) attached to the lower end of *Clymenella torquata* (Leidy) at Barnstable Harbor, Massachusetts. The present note documents the commensal relationship of *Montacuta floridana* Dall with the annelid *Onuphis magna* (Andrews). Specimens of these species in association were collected in a muddy sand bar about 200 yards south of the mouth of Hall's Creek (south of Matheson Hammock, Dade County, Florida). The burrows of *O. magna* at this locale were among *Thalassia* rhizomes. The substrate below the thin layer of detritus and mud was anaerobic.

Additional specimens from the northwest coast of Florida were obtained from Dog Island Reef (east of Dog Island, Franklin County) in depths from 5-20 feet in sand and sand-mud substrates. At these stations, adult *M. floridana* were found at the distal end of the tube constructed by *O. magna.*

Montacuta floridana was described and figured by Dall (1899, Proc. U. S. Nat. Mus., *21:* 873-897) from specimens found on the beaches of west Florida near the Manatee River by Charles T. Simpson. The type-lot consists of 6 specimens, 3 left and 3 right valves, all unmatched; the holotype (see Dall, pl. 87, fig. 10) consists of a right valve (USNM 64456).

Immature specimens from 0.5-1.0 mm. length of *M. floridana* from Hall's Creek are apparently attached to *Onuphis* and are ovate in outline. Allometric growth of the shell accounts for the difference in the shape of the valves of the adult clam which attains a length of 20 mm. and which is elongate. The dentition of this species consists of a protuberant cardinal tooth in the left valve which anteriorly interlocks with a similar tooth in the right valve. Posteriorly an internal resilial ligament conjoins the valves. The dentition is much like that of *M. phascolionis* Dautzenberg as illustrated by Deroux (1961, Cahiers Biol. Mar., Roscoff, *2:* 99-153, fig. 4). Anatomically the presence of single right and left ctenidia indicate the montacutid affinities of this species (Thiele, 1935, Handb. sys. Weichtierkunde, vol., 2, p. 874). One of us (Stewart) is preparing a detailed study of the anatomy, morphology, and ecology of this species. — K. J. Boss, Harvard University, N. K. Ebbs, Institute of Marine Science, University of Miami, and W. C. Stewart, University of California, Santa Barbara.

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Reprinted from Bulletin of Marine Science
Vol. 17, No. 1, March, 1967
pp. 85–94

NOTES ON *MALLEUS* (*PARIMALLEUS*) *CANDEANUS* (D'ORBIGNY) (MOLLUSCA: BIVALVIA)[1]

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Abstract

The relationships of the hammer oyster, *Malleus* (*Parimalleus*) *candeanus* (d'Orbigny), with other members of the Malleidae are considered, and some remarks on closely related forms in the Indo-Pacific region are presented. New data on the occurrence and ecology of *M. candeanus* are provided, and it is shown that the species lives attached to coral or coralline rock in relatively shallow water.

Introduction

The rarely encountered species, *Malleus candeanus* (d'Orbigny), is the sole representative of the genus in the western Atlantic. Not since the report of its occurrence in Bermuda by Johnson (1918) has this species been considered in any detail. As additional specimens have been collected, more data on the distribution and ecology of the species have become available. This information is summarized in this paper.

The species of *Malleus* form a distinct monogeneric family, the Malleidae (Newell, 1965) which is distinguished from other closely related members of the Pteriacea by the single, well developed, intrusive ligament, the posteroventrally directed growth form with its concomitant internal pallial rib, and the typical organic matrix of the distal portions of the shell. Anatomically, the animals possess a foot which is divided into an anterior elongated finger-shaped projection and a posterior byssus-bearing portion. Further, the pallial retractor muscles are conspicuously developed. The species of this genus are so similar to one another and form such a compact group that Thiele (1934) did not designate subgeneric divisions within the genus but only referred to the various infrageneric names introduced into the literature, particularly by de Gregorio (1884) and Iredale (1931).

The morphological bases of the subgeneric divisions of the Malleidae are open to question. Bilateral expansion of the hinge line is responsible for the well known hammer-shaped form of the Indo-Pacific *Malleus malleus* (Linnaeus). De Gregorio (1884, 1885) established *Malvufundus* upon the lack of a posterior lateral extension of the hinge line and *Fundella* upon the lack of both anterior and posterior hinge extensions. Similarly, Iredale (1931) proposed *Parimalleus*, a subjective synonym of *Fundella,* for those species which do not produce the hinge line laterally. He further (1939) characterized the species in this group as having a hinge line that is toothless or nearly so and in having the right valve plicate. Careful examination of specimens indicates that these criteria are too unstable to be reliable. Nevertheless, there appear to be two natural groups. One is the nominate subgenus *Malleus* s.s., typified by *M. malleus*, in which there are lateral, but not necessarily bilateral, extensions of the hinge line. There is also considerable posteroventral and posterodorsal growth beyond the limit of the nacreous inner shell. A weak or only moderately developed pallial rib is present, and there is no distinct ridge differentiating the nacreous shell and the posteroventral extension. Also, the external surface of the early shell is smooth or only slightly lamellose. The second group, *Parimalleus*, represented by *regula* (Forskål) and *candeanus*, is characterized by a highly lamellose early shell and a posterior elongate extension of an organic matrix from the nacreous shell with a strongly developed pallial rib on its inner surface. There is hardly any lateral extension of the hinge line and virtually no lateral extension of the horny matrix around the nacreous shell. Generally, the shells are divided into three distinct growth stages.

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Genus *Parimalleus* Iredale

Fundella de Gregorio, 1884: 72, pl. 4, fig. 6 (type-species by original designation *F. lioyi* de Gregorio, 1884, *non* Zeller, 1848 [Lepidoptera]).

Parimalleus Iredale, 1931: 205 (type-species by original designation *P. cursator* Iredale, 1931).

Brevimalleus McLean, 1947: 70 (new name for *Fundella* de Gregorio, 1884, *non* Zeller, 1848 [Lepidoptera]).

SPECIES OF *Parimalleus*

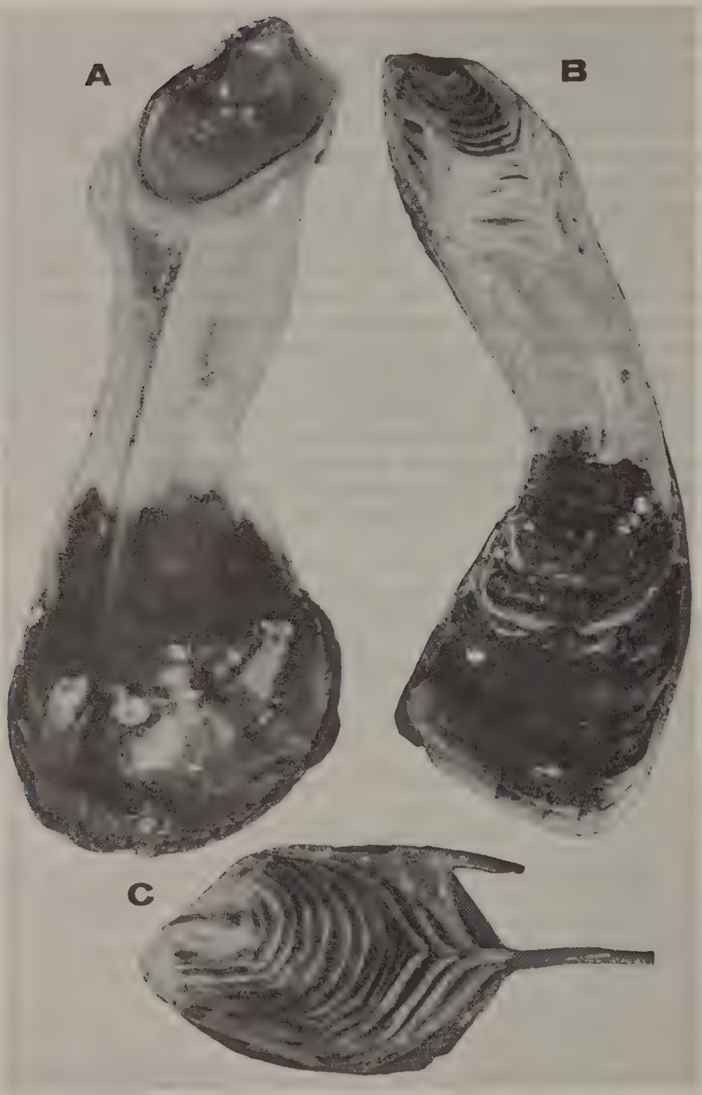
Parimalleus occurs throughout the world in tropical and subtropical waters, excepting West Africa. Although we can not present a critical revision of the species of *Parimalleus*, we can point out that there are two areas in which the subgenus is represented. In the eastern Pacific-western Atlantic region, *M. candeanus* is the only species representing the subgenus, and the four names available for the eastern Pacific population, *i.e., rufipunctatus* Reeve, *aquatilis* Reeve, *vesicularis* Reeve, and *obvolutus* de Folin are all synonyms of *M. candeanus*, a situation recognized by Johnson (1918) and Keen (1958). In the Mediterranean-Indo-Pacific region, *M. regula* appears to be the best known species. Although *P. lioyi* (de Gregorio), taken off the coast of Tunisia in the Mediterranean, has been included within the synonymy of *M. candeanus* by Johnson (1918), we believe that *P. lioyi* may really belong to the *M. regula* complex. Barnard

(1964) has shown that *M. regula* ranges throughout the Indo-Pacific region. The status of the Australian species *P. rex, P. gregarius,* and *P. cursator,* all described by Iredale, appears to be dubious. In Japan, in addition to *M. regula,* Habe (1951, 1953) recorded *P. irregularis* (Jousseaume), a species that is very similar to *M. regula.* Dall *et al.* (1938) gave extensive Hawaiian records for *M. nuttalli* (Conrad), which has been recently included in the concept of *M. regula* by Barnard (1964).

For extensive and exhaustive synonymies of the malleids, Prashad (1932) is unexcelled. His treatment of *M. regula* shows it to be widely ranging in the Indo-Pacific region, including the Red Sea. The major problem with *Parimalleus* is whether or not there is only a single extremely variable species in the Mediterranean-Indo-Pacific region, and if so, whether that species can be truly differentiated from *M. candeanus.* With the study material at hand, we are able to discern a few feeble differentiating characteristics which may separate the New World populations of *M. candeanus* from the Indo-Pacific *M. regula.* The tripartite division of the growth form in *M. candeanus* is more distinct, the shank portion being somewhat more markedly constricted in more individuals. Similarly, the fan-shaped posterior portion is somewhat wider in specimens of *M. candeanus.* Many Indo-Pacific specimens of the *M. regula* complex have a much thinner and more translucent calcareous shank stage.

Malleus (*Parimalleus*) *candeanus* (d'Orbigny)

Avicula candeana d'Orbigny, 1842, atlas of plates: pl. 28, figs. 25-27; 1845, Spanish text, p. 358; 1853, French text, vol. 2, p. 343 (type-locality, Santiago de Cuba in sponges).
Malleus candeanus, Beau, 1858: 21 (Guadeloupe).
Malleus rufipunctatus Reeve, 1858: pl. 3, fig. 8 (type-locality, West Colombia).
Malleus aquatilis Reeve, 1858: pl. 3, fig. 11 (type-locality, Isle of Plata, West Colombia).
Malleus vesiculatus Reeve, 1858: pl. 3, fig. 12 (type-locality, Isle of Plata, West Colombia).
Malleus panamensis Mörch, 1861: 209 (type-locality, Puntarenas, Costa Rica, on *Pinctada*).
Avicula candeana, Krebs, 1864: 131 (Cuba, de Candé; Guadeloupe, Beau).
Malleus obvolutus de Folin, 1867: 27, pl. 4, figs. 6-8 (type-locality, Pearl Islands, Bay of Panama).
Avicula candeana, Schramm, 1869: 22 (Guadeloupe).
Avicula candeana, Arango y Molina, 1878: 268 (Cuba).
Avicula candeana, Mörch, 1878: 16 (no locality).
Malleus (*Fundella*) *candeanus,* Fischer, 1887: 954.
Electroma candeana, Dall, 1898: 668 (Antilles).
Fundella candeana, Johnson, 1918: 37-39, pl. 3 (Bermuda).
Fundella candeana, Johnson, 1934: 22 (Bermuda, Bryant; Cuba, d'Orbigny).
Parimalleus rufipunctatus, Keen, 1958: 60, fig. 109 (Mazatlán, Mexico to Panama).
Malleus panamensis, Keen, 1966: 5, fig. 3.


A
B
C

DISTRIBUTION AND ECOLOGY OF *M. candeanus* IN THE WESTERN ATLANTIC

Basing their statements on the original information presented by d'Orbigny (1845), some authors (Dall, 1898; Keen, 1958) alluded to the possible commensal habitat of *M. candeanus* with sponges. Other authors (de Folin, 1867; Johnson, 1918; Keen, 1958) stated that *M. candeanus* lives attached to coralline rock or to shells such as *Ostrea.* None of the specimens we have examined were found living in association with sponges. Our data suggest that *M. candeanus* lives attached to hard substrates, particularly in the crevices of coral or coralline rock. Specimens from Harrington Sound, Bermuda, were found on the coral *Agaricia fragilis* (Dana), and the individual illustrated in Figure 1 C from between Molasses Reef and Key Largo, Florida, was taken from the underside of a colony of the coral *Colpophyllia natans* (Muller). Specimens from Loggerhead Key, Florida, were attached to the calcareous alga *Neogonialithon.*

The species was thought to have a restricted bathymetric range. Apparently, most specimens have been taken in shallow water, in as little as 0.3 m in the Virgin Islands. However, a specimen from Mona Passage was taken alive from a depth of 437-546 m. The next deepest record for living material is 47 m from Campeche Bank, Gulf of Mexico. The depth record of the Mona Passage specimen far exceeds that of any other living material of *M. candeanus.* Figure 2 illustrates the known records of *M. candeanus* in the western Atlantic. The species occurs from Bermuda south through Florida and the Antilles and west to the Gulf of Campeche.

SPECIMENS EXAMINED

MCZ—Museum of Comparative Zoology, Harvard University, Cambridge, Mass.

USNM—United States National Museum, Washington, D. C.

BERMUDA: (MCZ 73634).—0.5 mile S of North Rock, 2.75 m (MCZ 218424).—1.7 miles SW of North Rock, 3.6-5.5 m (MCZ 168777).—Harrington Sound, 1-1.5 m (MCZ 233815).

←

FIGURE 1. *Malleus* (*Parimalleus*) *candeanus* (d'Orbigny). A—Internal view of the left valve showing the pallial rib and the raised ridge separating the nacreous inner shell and the secondary calcareous shank stage, USNM 671229, (about 3.8 ×, actual length 31.5 mm). B—External view of the left valve showing the three distinct structural stages: the heavily sculptured early stage, the narrow calcareous shank stage, and the final fan-shaped horny shell stage, USNM 671229 (about 2.35 ×, actual length 48.0 mm). C—External view of the left valve of immature specimen in the early stages, USNM 671226 (about 4.1 ×, actual length 17.5 mm).

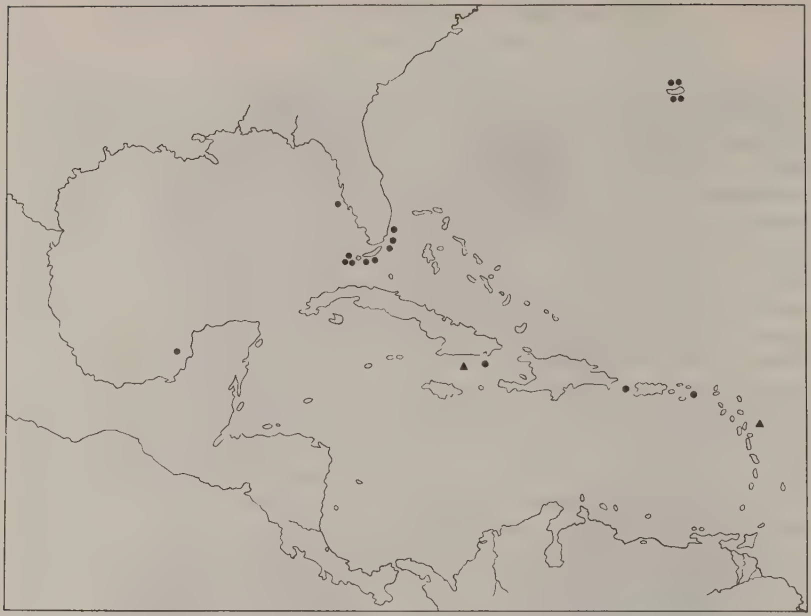


FIGURE 2. Distribution of *Malleus* (*Parimalleus*) *candeanus* (d'Orbigny) in the western Atlantic. Solid circles indicate records for specimens examined; triangles indicate records from the literature.

FLORIDA: Pompano Beach (MCZ 168678).—E of Cape Florida, 25°40′ N, 80°05′W, 14-18 m (USNM 671228).—E of Cape Florida, 25°39′N, 80°05′W, 18 m (USNM 671229).—patch reef between Molasses Reef and Key Largo, 2.4 m (USNM 671226).—Off Pelican Shoal, 81 m (MCZ 232947).—Garden Key, Dry Tortugas (MCZ 232931).—EOLIS sta. 36, Southwest Channel, Dry Tortugas, 18 m (USNM 457011).—Loggerhead Key, Dry Tortugas (MCZ 232939).—Middle Grounds, NW of John's Pass, off St. Petersburg (MCZ 237025).

MEXICO: SILVER BAY sta. 961, 20°02′N, 91°58′W, off Arcas Cays, Bay of Campeche, 47 m (USNM 671227).

GREATER ANTILLES: Guantánamo Bay, Cuba (MCZ 213464).—Johnson-Smithsonian Deep Sea Expedition sta. 43, 18°02′00″N, 67°51′15″W to 18°03′45″N, 67°48′10″W (USNM 430709). According to Bartsch, 1933, Smithsonian misc. Coll. *91* (1): 12, "When the tangle was put overboard at 1:00 p.m., Mona Light bore 8° and Punta Caigo ó no Caigo 297°. The depth varied from 240 to 300 fathoms [439-549 m].

The haul yielded two species of stalked crinoids; a lot of comatulid crinoids; a mass of echinoids; brittlestars, including a few astrophytons; corallines; hydroids; sponges; and a few mollusks." This locality is off Mona Island, in Mona Passage between Santo Domingo and Puerto Rico. The specimen was alive, but the nature of the substrate to which it was attached is unknown.

VIRGIN ISLANDS: Christian Cove, Great St. James Island, 0.3-3 m (MCZ 219449).

THE GROWTH FORM OF *M. candeanus*

The completed growth form of *M. candeanus* is illustrated in the almost perfectly developed specimens in Figure 1 (A and B). There are three distinct portions in the fully developed adult. The early shell, which is formed following the prodissoconch stage, is externally lamellose. Internally the fully developed primary and nacreous shell subtends the lamellose stage. At first the lamellations are formed concentrically, but later in ontogeny they converge in a V-shaped configuration which in turn forms the foundation for the pallial rib, the development of which is most characteristic in stage two. The second or calcareous shank stage is typically pure white in color, probably totally composed of shelly matter and characteristically provided with an anteroposterior longitudinal pallial rib on the posterodorsal portion of its inner surface. The third and final stage or portion is the fan-shaped distal extension of the shell which is composed of a horny substance much like that of the peripheral areas in *Isognomon* and other pteriacean bivalves.

The two latter stages are not always developed in all specimens. Further, the axis of growth of the distal stage may be altered, *i.e.*, it may be at an angle of up to 90° to the anteroposterior axis. Certainly the complete expression of the genotype responsible for this unique ontogeny may be limited by environmental factors. For example, a larva that settles in a crevice in coral may not be able to grow distally along the anteroposterior axis and grows instead at an angle to it.

The internal pallial rib is the demarcation line along which the axis of the ctenidia extends when the mantle, pallial musculature, and ctenidia are fully expanded to reach the distal portions of the shell. The mantle and the ctenidia are capable of being retracted into the proximal portions of the shell by the elongate specialized pallial muscles (Pelseneer, 1911; Kühnelt, 1938).

The unique growth form of *M. candeanus* is certainly of adaptive significance. The animal feeds by drawing suspended matter toward the mouth along the ctenidia. The distal fan-shaped extension of the shell must afford considerably more area for feeding and direct contact of the mantle and ctenidia with the environment.

ACKNOWLEDGMENTS

Loan of specimens was made by Dr. W. J. Clench of the Museum of Comparative Zoology, Harvard University. The corals and coralline algae were identified by Mr. P. Lowe and Dr. W. Adey, respectively, of the U. S. National Museum. The manuscript was critically reviewed by Drs. J. Rosewater and H. A. Rehder of the U. S. National Museum, and by Dr. D. Cohen of the Bureau of Commercial Fisheries Ichthyological Laboratory. R/V SILVER BAY specimens were collected from boulders brought to the junior author by Mr. J. B. Rivers. This work was supported in part by National Science Foundation grants GB-3104 and BP-2455.

SUMARIO

NOTAS SOBRE *Malleus* (*Parimalleus*) *candeanus* (D'ORBIGNY) (MOLLUSCA: BIVALVIA)

Se consideran las relaciones de *Malleus* (*Parimalleus*) *candeanus* (d'Orbigny) con otros miembros de la familia Malleidae, y se presentan algunos apuntes de formas estrechamente relacionadas, en la región del Indo-Pacífico. Se aportan nuevos datos sobre la presencia y ecología de *M. candeanus*, y se muestra que la especie vive adherida a corales o rocas coralinas en aguas relativamente bajas.

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Swimming Behavior of Fishes

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A goldfish and an aquarium, standard equipment in most science rooms, can be used to show the importance of sight in the orientation of fish. This easy demonstration can do much to stimulate interest in the classroom.

Introduction

In the past few years, fishery scientists have expended considerable effort in determining the swimming abilities of various species of fish. Their investigations have been concerned primarily with 1) determinations of swimming speeds of commercial fish in relation to development of fishing gear, and 2) movement of fish through fish passages of water-power dams. The information obtained from the investigations has been valuable in recommending more efficient trawling methods to fishermen, and has been used to assist engineers and scientists in the design of fishways.

A fish uses its body (or trunk) for locomotion. The tail (caudal fin) functions as a motor and the remaining fins are used for steerage and balance. Insight as to how a fish swims has been obtained from studies with machines. Most machines apply power by means of wheels or shafts rotating about a fixed axis, usually at a constant speed. In animals this arrangement is impossible, since all parts of the body must be connected by blood vessels and nerves. When fish use their trunks to move through the water, they use the backbone (vertebrae) as a lever. Muscles are the power sources which pull and push the lever by contraction. Each vertebra is hinged to the next vertebra in such a way that movement is possible only in a single plane. A fish moves forward by sweeping its tail sideways. The force of the tail against the resistance of the water produces a resultant force that propels the fish forward. As the tail sweeps in one direction, the front end of the body, since it is on the opposite side of the hinge, must tend to swing in the opposite direction (Fig. 1).

Controlled studies of swimming speed have clearly demonstrated that the speeds of some fish are much slower than most people believe. When a stationary herring, alewife, trout, or bass is startled, it appears to move off at an extremely high speed. The human eye is very unreliable, however, for judging the rate of this sudden movement. Until a few years ago, few reliable observations were available concerning

Reprinted from THE AMERICAN BIOLOGY TEACHER, Vol. 29, No. 6, September, 1967

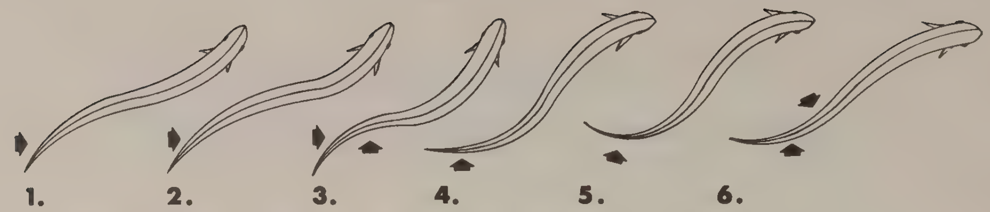

Fig. 1. Illustration of method by which a fish exerts force against its medium.

speeds of fish of known size and weight. Many records were obtained by timing the movements of fish from ships at sea or by estimating the speed of fishing lines running out after hooked fish. Speeds ranging from 25 miles an hour for salmon to 68 miles per hour for sailfish were reported. Recent experimental tests refute the results of these findings and indicate that fish do not have as great powers of locomotion as was previously believed (Table 1).

Species	Length (feet)	Maximum observed speed (miles per hour)
Cod	0.4–1.8	1.7–4.9
Goldfish	0.3–0.4	1.5–3.5
Haddock	0.8–1.4	1.7–4.0
Herring	0.4–0.8	0.1–3.8
Mackerel	1.1–1.3	4.2–6.7
Saithe	0.3–0.7	1.4–4.5
Sea trout	0.4–1.3	3.0–7.1
Whiting	0.5–0.7	1.7–3.5
Brook trout	0.7–1.0	3.8–6.5
Pike	0.5–0.7	3.3–4.7
Barracuda	4.0	27.3
*Dolphin	7.0	22.4
*Whale	90.0	20.0

*Mammal

To investigate swimming ability of fish, laboratory experiments using longitudinal and circular troughs are conducted on the premise that fish provided with a fixed visual reference point will swim in a direction opposite to the movement of the water, in a manner similar to their behavior in a stream. In the longitudinal trough, fish when provided with a visual reference point (fixed object) and subjected to inflowing water maintain their position by swimming against the current. In the circular trough, the fish's environment is moved in a path opposite to the fish's movement. Provided with a visual reference point, the fish swims against the current. In a stream, the current tends to force the fish downstream, and in the troughs, backward. In either, the fish opposes the movement of water and swims, exerting enough energy to keep its same visual field. Tests have shown that fish will orient against various water movements, but that this response is dependent on the fish's size and the water velocity. If the current is not great enough, the fish swims in all directions until the flow of water has been increased. Fish can be deceived into believing a current is present when one is actually lacking. Fish placed in a circular trough (with no current) will follow a screen with black stripes passing underneath or beside him; if a current is introduced, the fish will swim in the opposite direction.

As indicated, fish swim against a current when they are provided with a visual reference point. Experiments with blind goldfish in troughs have indicated that touch as well as sight may be used for orientation against a current. Blind goldfish when subjected to currents swim in various directions until some part of their body contacts either the sides or bottom of the experimental troughs. Immediately upon contact, the fish orients against the current. The question of how a fish in the open ocean determines whether it is going in the "right" direction has not been answered as yet. Many theories have been proposed, but to date no satisfactory or tested answer is available. Probably the best guess is that the stars, moon, and sun serve as navigational aids.

Troughs have been used also to determine swimming speeds. In each trough (longitudinal or circular), fish are subjected to different water velocities. To avoid being swept backward, the fish swims at the necessary speed. An increase in water velocity forces the fish to swim faster. When the fish cannot keep up with the current and begins to lose ground continuously, its maximum speed has been reached. In the field, cages with fish have been towed underneath a boat at given speeds. Such experiments, monitored by a television camera, have provided information on swimming abilities of various species. In these experiments fish swam against the current (the cage itself was the reference point) until they becamed pinned against the rear screen of the cage. The speed at which the cage was towed was the estimate of the maximum swimming speed of the fish. One novel instrument used to test speeds of fish is the Piscatometer, a special fishing rod and reel by which velocity of a line-hooked fish can be measured. Knowledge of the rate the line runs out and of the added drag of the line allows measurement of speeds of large fish.

Demonstration

The importance of sight in the orientation of fish can be demonstrated in the laboratory.

Materials:

1. Rectangular aquarium (5 gallon capacity or greater) with glass bottom.
2. Four block supports for the aquarium (2-inch cubes).
3. Fish: preferably a goldfish, stickleback, or mummichog.
4. White cardboard with 1/2-inch black stripes. The dimensions of the cardboard should be only slightly less than the dimensions of the aquarium. Either two or three stripes can be painted on the cardboard, the distances between the stripes should be equal.
5. Data sheet to record orientation (positive or negative).

Methods:

Place the aquarium on the supports so that the cardboard can be gently pulled across the bottom of the aquarium.

Expected Results

The fish tested orients with the head in the direction of the moving cardboard and swims along with it. If the movement of the cardboard is reversed, the movement of the fish also is reversed. In nature, a fish must exert energy and swim against the current to avoid being swept downstream. In the aquarium the fish moves in the same direction as the moving card, which might be viewed as a fixed object in the stream.

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Reprinted from Transactions of the American Fisheries Society
Vol. 96, No. 3, 21 July 1967
pp. 361–363

An Automatic Device for Counting Dry Fish Eggs

An automatic device for counting dry fish eggs is now in use at the U. S. Bureau of Commercial Fisheries Biological Laboratory, W. Boothbay Harbor, Maine. Our studies of fecundity of Atlantic herring (*Clupea harengus harengus* L.), which may contain as many as 140,000 eggs, required a counting system which would enumerate eggs rapidly and accurately. Since the conventional volumetric and gravimetric methods were too laborious, we tested several automatic egg counters. Initially, we used a wet system modified after Parrish, Baxter, and Mowat (1960) and Davis and Paulik (1965). Although this system met our requirements, the equipment required the periodic attention of a technician to prevent clogging of eggs. To improve efficiency, we tested the "Decca Mastercount,"[1] a machine that records dry eggs as they pass a photoelectric cell. It counts 10,000 herring eggs in 5 minutes with an accuracy of 95%, and can be left unattended while in operation.

The Decca Mastercount consists of two units; the integral feeder detector and the master counter (Figure 1). The eggs are moved by vibration in single file over the sizing groove (3), through the aperture of the detector (4), and past the beam of the photoelectric cell (5) which transmits the record to the counter. The eggs accumulate in the receptacle (6). The operation of the system involves placing the eggs in the feeder bowl (2) and adjusting the sensitivity control (9), the sizing groove (3), and the vibration control (1). After these adjustments, the operator can turn on the main switch (8), leave the system operating, and perform other duties. After the count has been completed, the receptacle is removed (which stops the system's operation) and the eggs in the receptacle can be either stored or discarded. A new batch of eggs is placed in the feeder bowl, the reset button (7) is pressed, and the receptacle reinserted; the system begins without further adjustments. If eggs which differ in size by 0.3 mm or more are to be counted, the sizing groove is set to allow only the smaller eggs to reach the aperture. Larger eggs are then rejected into the feeder bowl. When all the small eggs have been counted, the receptacle is removed. The sizing groove is adjusted to allow the larger eggs to be counted, the receptacle is reinserted, and the count begins.

We prepare the eggs for counting by first placing the ovaries in Gilson's fluid. After 1 week the jars containing the ovaries and fluid are placed in a small ultrasonic cleaning tank and subjected to high-frequency sound waves (30 KC) for 15 to 20 minutes. The vibration of the sound waves separates the

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[1] Trade names referred to in this publication do not imply endorsement of commercial products.

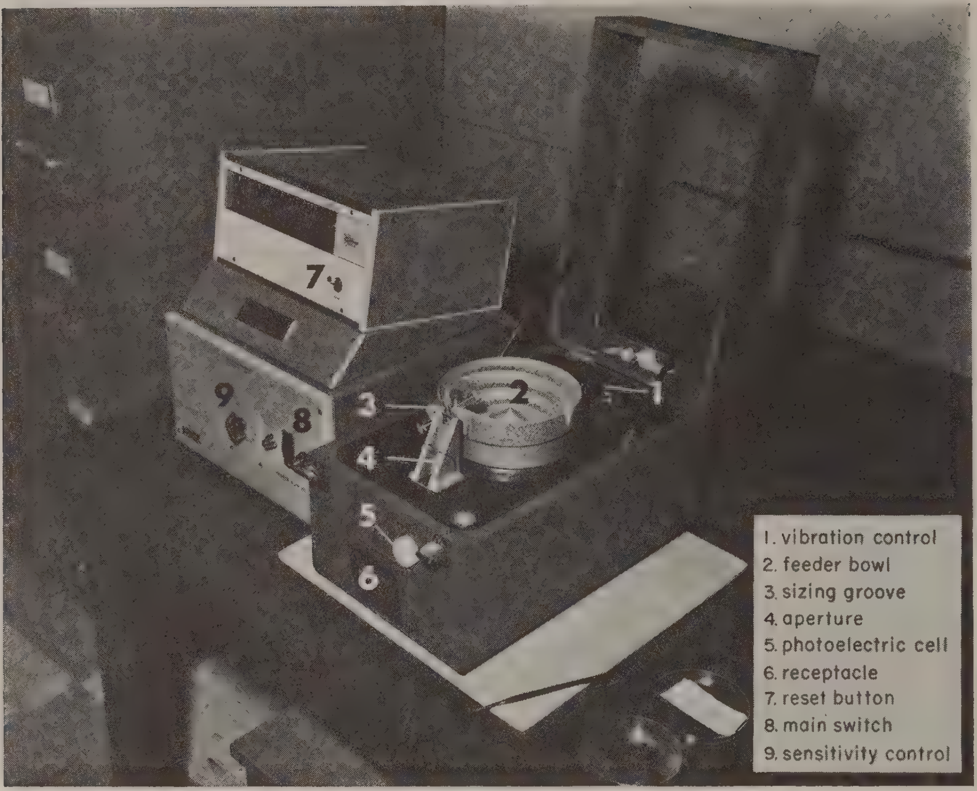
7
9
8
3
2
1
4
5
6
1. vibration control
2. feeder bowl
3. sizing groove
4. aperture
5. photoelectric cell
6. receptacle
7. reset button
8. main switch
9. sensitivity control

FIGURE 1.—Decca Mastercount Unit for counting dry fish eggs.

eggs from the ovarian tissue. The eggs are washed free of the ovarian tissue and dried in a petri dish for 24 hours. They are then ready for counting.

To test the accuracy of the system in counting eggs of different sizes and at different speeds, we manually counted batches of 2,000 and 50,000 herring eggs, and 1,700 eggs of brown trout (*Salmo trutta* L.). The herring eggs averaged 0.9 mm in diameter and the trout eggs 5.0 mm. As expected, an increased speed of egg flow increased the percentage

TABLE 1.—*Counts of known numbers of fish eggs made at various speeds with a Decca Mastercount*

Test number	Herring						Trout
	2,000 eggs			50,000 eggs			1,700 eggs
	20/sec.	30/sec.	35/sec.	20/sec.	30/sec.	35/sec.	20/sec.
1	1,998	1,972	1,904	49,837	48,941	48,194	1,698
2	2,000	1,968	1,902	49,700	48,770	47,831	1,697
3	1,996	1,972	1,901	49,800	48,835	47,387	1,699
4	1,997	1,973	1,915	49,777	48,697	47,521	1,700
5	1,998	1,966	1,922	49,632	48,915	47,441	1,699
6	1,997	1,971	1,918	49,841	48,850	47,477	1,700
7	1,996	1,964	1,910	49,715	48,650	48,141	1,700
8	1,997	1,975	1,922	49,634	48,552	48,005	1,698
9	1,998	1,969	1,918	49,652	48,602	47,521	1,700
10	1,998	1,970	1,928	49,857	48,700	47,620	1,700
Mean	1,997.5	1,970.0	1,914.0	49,744.5	48,751.4	47,713.8	1,699.1
% Error	0.02	1.5	4.3	0.51	2.5	4.6	0.05
Standard deviation	1.2	3.3	9.33	88.78	132.38	295.21	1.1

of eggs that were not counted. This error which was always negative occurred when more than one egg passed the beam of the photoelectric cell at the same time. For herring eggs the error of the mean was greater than 5% only when the speed exceeded 35 eggs per second (Table 1). At 20 eggs per second, the error was less than 1%. Trout eggs were counted with an accuracy of 99% at 20 per second (the maximum speed at which they could be counted because of their large size).

Our method of counting eggs with a Decca Mastercount offers several advantages over an automatic wet method. The operator is free to perform other duties and needs little training to operate the equipment. The system is adjustable to eggs of different sizes, is compact, and is easily portable.

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C. REPORT ON THE INVESTIGATIONS BY THE UNITED STATES FOR THE INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION—1965

U.S. Bureau of Commercial Fisheries
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INTRODUCTION

In 1965 research by the United States for the International North Pacific Fisheries Commission (INPFC) followed essentially the same lines as in 1964. Activities included research on (1) distribution, relative abundance, and migrations of high seas salmon, (2) areas of origin of high seas salmon, (3) the ocean environment and its influence on salmon, (4) ocean mortality and growth of salmon, and (5) king crab stocks of the eastern Bering Sea. Intensive field tests were started to determine mortality of salmon during their last few weeks of ocean life and rates of dropout (salmon caught but not landed) during high seas gillnetting.

This report describes the progress on investigations in 1965. As in past years, studies on tagging and sampling were carried out by the Fisheries Research Institute, University of Washington, under contract to the Bureau of Commercial Fisheries. Research on eastern Bering Sea stocks of king crab is being conducted by the Bureau's Biological Laboratory, Auke Bay, Alaska. The remainder of the work was done by the Bureau's Biological Laboratory, Seattle. Two manuscripts by the Seattle Biological Laboratory describing research findings for 1956–60 on eastern Bering Sea king crabs are to be submitted for publication in 1966.

The United States is cooperating in groundfish studies on Bering Sea and Gulf of Alaska stocks with Canada, Japan, and the International Pacific Halibut Commission. Progress in these studies is reported in the Proceedings of the Twelfth Annual Meeting (1965) of the International North Pacific Fisheries Commission.

TAGGING AND SAMPLING

by A. C. Hartt, L. S. Smith, and M. B. Dell

The Fisheries Research Institute of the College of Fisheries, University of Washington, under contract to the U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, sampled and tagged salmon on the high seas in a program similar to that of 1964. Tag recovery effort in 1965 was similar to that in earlier years except that the reward for tags recovered in the year of release was increased from $1 to $3 to conform to practices of the Bureau of Commercial Fisheries. Advertising and visitation work to promote recoveries in the Bristol Bay area was handled by personnel of the Bureau of Commercial Fisheries since they were engaged in the recovery of large numbers of tags from their mortality and growth experiments. The 1965 work is described under the following three main headings: (1) Gulf of Alaska longlining; (2) Central Aleutian purse-seine indexing; and (3) seining of fingerling salmon in the Gulf of Alaska.

GULF OF ALASKA LONGLINING

Objectives were to fish and tag over wide areas of the Gulf starting early in the season to compare abundance, distribution, and migrations of salmon (mainly mature) with those in earlier years. This longline operation was coordinated with similar operations by Canada and by Japan. Some samples of sockeye salmon (1,638) were frozen and sent to the Fisheries Research Board of Canada's Biological Station at Nanaimo, British Columbia, for racial identification by means of meristic characters and parasites. Canada kindly loaned a brine freezer and cold storage boxes for installation on the vessel *Storm*. Some pink salmon (381) were preserved by salting and sent to Nanaimo to determine vertebral counts for use in identification of stocks. A secondary objective was to fish with a purse seine in the southern part of the Gulf of Alaska to extend our knowledge of the early-season migrations of immature sockeye and chum salmon. Operations by U.S. vessels for the above work were as follows:

Vessel	*Dates of operation*	*Gear*
Commander	April 10–June 7	Longline (principal gear) Purse seine (secondary gear)
Storm	April 20–July 12	Longline
Karen T.	May 21–July 3	Longline

The joint longline sampling and tagging in the Gulf of Alaska was the most comprehensive to date. Three Canadian and three U.S. boats repeatedly sampled a grid of stations between lats. 43°N and 59°N, westward to long. 155°W. After May 20 most fishing was in the northern and eastern Gulf. Canadian vessels operated from April 1 to June 7. Two Japanese vessels fished in the northwestern part of the Gulf at a series of stations between Adak and Kodiak in late May. Details of the Canadian and Japanese operations are available in other parts of the Annual Report.

In general, the catches in 1965 indicated distribution and seasonal migration similar to that of earlier years. Numbers caught and tagged by U.S. vessels in the Gulf longline operation are listed by statistical area in Table 1.

Mature sockeye salmon were most abundant in the northwestern Gulf of Alaska in April and May (north of lat. 50°N and west of long. 140°W) and apparently many shifted westward as the season progressed. Scale examinations showed a high proportion of fish of the Bristol Bay type in the northwestern Gulf through June 10. Subsequently tag returns verified the importance of Bristol Bay stocks in this area. In April and early May the immature sockeye occurred mainly south of lat. 50°N, extending to about 46°N; they shifted northward with the season.

Chum salmon were dispersed widely throughout the sampling period and showed little evidence of concentration. Immature chum salmon were farther to the south than the mature fish, as noted above for immature sockeye salmon.

Pink salmon were located in April in a belt approximately between lats. 43° and 50°N. The greatest abundance was in the eastern half of the Gulf. In May and June the areas of greatest abundance shifted northward, particularly in the eastern Gulf. General abundance through June 15, where data could be compared, was slightly less than in the previous cycle year (1963). Catches in the northern Gulf were clearly less than in 1963; the drop presumably indicates a poorer early run in 1965. Catches in the extreme southeastern Gulf (east of long. 130°W) were also notably less than in 1963. Catches in July indicated a northwestward shift of pink salmon in the northern Gulf. Operations were ended before these stocks could be followed farther coastward, but tagging in earlier years has indicated fish in the north-central Gulf to be a mixture destined mainly for Kodiak Island, Cook Inlet, Prince William Sound,

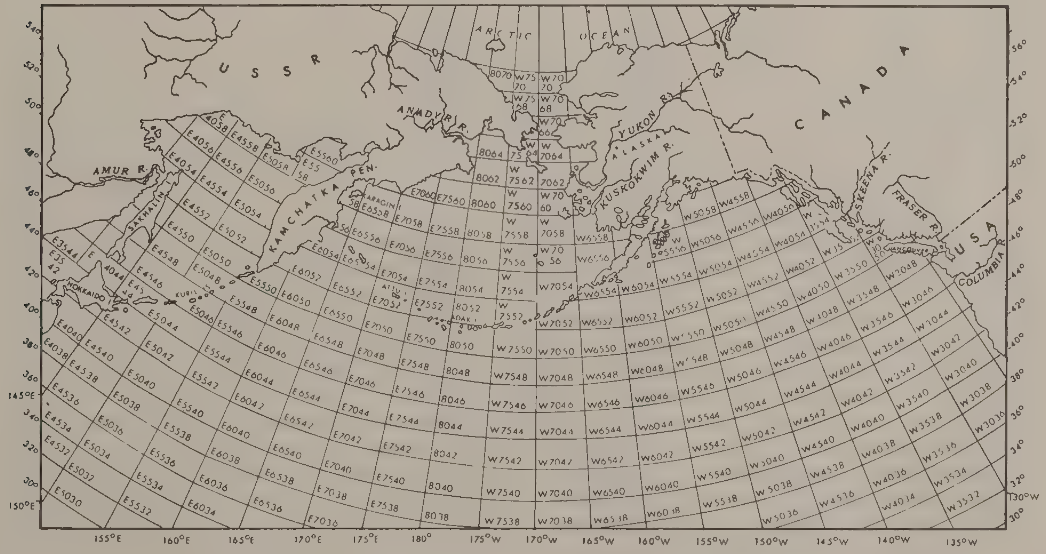


FIGURE 1. INPFC North Pacific area coding as modified for tagging.

TABLE 1. Longline and purse seine catch and tagging data by statistical areas, Fisheries Research Institute vessels, 1965.

LONGLINE OPERATIONS

Area (Fig. 1)	Inclusive dates	Number of longline sets	Total skates	Numbers caught and (in parentheses) numbers tagged						
				Sockeye	Chum	Pink	Coho	Chinook	Steelhead	Total
W7052	6/7	1	15	129(90)	4(4)	8(4)	0(0)	0(0)	0(0)	141(98)
W6054	5/23	1	20	281(47)	5(5)	0(0)	0(0)	0(0)	0(0)	286(52)
W6052	6/4	1	20	76(6)	4(3)	4(4)	0(0)	0(0)	0(0)	84(13)
W6050	5/25	1	10	21(0)	3(1)	0(0)	0(0)	0(0)	0(0)	24(1)
W6048	5/26—5/27	2	40	60(2)	21(13)	30(17)	0(0)	0(0)	9(7)	120(39)
W5558	5/28	1	11	10(9)	19(16)	0(0)	0(0)	0(0)	0(0)	29(25)
W5556	5/20—6/30	3	60	276(119)	52(45)	6(4)	0(0)	0(0)	0(0)	334(168)
W5554	5/14—7/1	4	65	131(0)	20(15)	10(9)	0(0)	0(0)	0(0)	161(24)
W5552	6/4	1	15	16(12)	1(1)	3(3)	0(0)	0(0)	0(0)	20(16)
W5550	5/10—6/3	5	84	187(20)	31(28)	41(34)	0(0)	0(0)	3(2)	262(84)
W5548	5/28	1	20	10(0)	5(5)	24(15)	0(0)	1(0)	18(18)	58(38)
W5546	4/23—4/24	2	30	0(0)	6(5)	11(3)	0(0)	0(0)	0(0)	17(8)
W5544	4/22	1	19	0(0)	0(0)	2(1)	0(0)	0(0)	0(0)	2(1)
W5058	5/31—6/15	3	31	68(45)	12(12)	0(0)	0(0)	0(0)	1(0)	81(57)
W5056	5/25—6/13	6	63	363(170)	15(9)	3(1)	0(0)	0(0)	0(0)	381(180)
W5054	6/13—7/2	2	30	28(0)	3(3)	14(13)	0(0)	0(0)	1(0)	46(16)
W5052	5/13—6/14	3	60	399(0)	15(8)	50(47)	0(0)	0(0)	2(2)	466(57)
W5050	5/11—6/2	3	45	242(33)	28(22)	44(27)	0(0)	0(0)	2(1)	316(83)
W5048	5/8—5/29	2	40	156(6)	10(7)	33(20)	0(0)	1(0)	11(8)	211(35)
W5046	4/25	1	10	0(0)	3(2)	1(1)	0(0)	0(0)	0(0)	4(3)
W5044	4/21	1	10	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
W4558	6/1—6/28	6	80	104(60)	90(76)	56(48)	5(5)	0(0)	1(0)	256(189)
W4556	5/23—7/5	7	78	264(102)	105(86)	170(155)	9(5)	0(0)	7(7)	555(355)
W4554	6/15—7/6	3	48	101(9)	20(14)	81(66)	10(8)	1(0)	9(6)	222(103)
W4550	5/13	1	10	10(10)	5(4)	7(5)	0(0)	0(0)	4(4)	26(23)
W4548	5/7—6/1	3	45	59(23)	21(16)	31(20)	4(4)	0(0)	19(13)	134(76)
W4546	4/26—5/31	5	60	11(6)	53(31)	65(32)	4(4)	0(0)	20(18)	153(91)
W4544	4/19	1	10	0(0)	1(0)	16(11)	0(0)	0(0)	0(0)	17(11)
W4542	4/20	1	10	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
W4058	6/4—6/26	5	67	13(8)	25(15)	125(85)	5(2)	0(0)	0(0)	168(112)
W4056	5/22—6/25	7	79	38(20)	16(8)	219(150)	8(7)	0(0)	3(3)	284(188)
W4054	6/18—7/7	2	30	52(0)	9(7)	95(69)	4(4)	0(0)	4(2)	164(82)
W4052	6/17—6/29	2	30	24(0)	9(5)	94(78)	4(1)	0(0)	4(2)	135(86)
W4048	5/30	1	15	2(1)	15(12)	37(25)	7(3)	0(0)	1(1)	62(42)
W4046	4/27—5/17	6	88	40(22)	30(19)	94(40)	4(2)	0(0)	21(15)	189(98)
W4042	4/18	1	10	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
W3552	6/19—6/30	2	20	2(0)	6(4)	48(44)	6(3)	0(0)	2(1)	64(52)
W3548	5/8—7/9	3	55	17(4)	51(29)	49(31)	13(12)	1(0)	3(3)	134(79)
W3546	4/24—5/19	6	59	1(1)	27(14)	97(27)	3(2)	0(0)	4(2)	132(46)
W3542	4/16—4/17	2	20	0(0)	0(0)	0(0)	1(0)	0(0)	0(0)	1(0)
W3048	4/22—7/2	3	41	5(3)	0(0)	0(0)	6(3)	0(0)	0(0)	11(6)
W3046	5/1—7/10	6	84	0(0)	0(0)	0(0)	3(2)	0(0)	4(2)	7(4)
W3042	4/15	1	8	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
W2548	5/27	1	14	0(0)	0(0)	0(0)	5(5)	1(1)	1(1)	7(7)
W2546	5/2—7/11	2	34	0(0)	0(0)	0(0)	45(30)	1(0)	0(0)	46(30)
W2544	4/12	1	5	0(0)	0(0)	2(1)	0(0)	0(0)	0(0)	2(1)
W2542	4/13	1	10	0(0)	0(0)	0(0)	0(0)	0(0)	1(1)	1(1)
Longline totals										
(*47 areas*)	4/12—7/11	124	1708	3196(822)	739(544)	1571(1090)	146(104)	6(1)	155(119)	5813(2680)

Continued . . .

Table 1. (Continued).

PURSE SEINE OPERATIONS

Area (Fig. 1)	Inclusive dates	Number of purse seine sets	Numbers caught and (in parentheses) numbers tagged						
			Sockeye	Chum	Pink	Coho	Chinook	Steelhead	Total
8050	6/10—8/17	67	4081 (3923)	5178 (1916)	1639 (794)	96 (72)	72 (49)	3 (3)	11069 (6757)
W7550	6/25	1	3 (3)	12 (12)	44 (44)	0 (0)	0 (0)	0 (0)	59 (59)
W7052	6/7—6/23	4	218 (204)	124 (105)	124 (107)	1 (1)	0 (0)	0 (0)	467 (417)
W5558	8/12—8/14	6	276 (84)	6 (5)	35 (9)	59 (21)	11 (10)	0 (0)	387 (129)
W5556	8/14—8/15	8	86 (36)	53 (29)	488 (308)	34 (6)	4 (3)	0 (0)	665 (382)
W5060	8/21	2	10 (0)	0 (0)	4 (0)	11 (4)	6 (6)	0 (0)	31 (10)
W5058	8/9—8/11	3	70 (60)	5 (5)	488 (405)	11 (8)	1 (1)	0 (0)	575 (479)
W4558	8/8	2	449 (348)	42 (15)	46 (31)	31 (25)	5 (0)	0 (0)	573 (419)
W4550	5/13	1	0 (0)	0 (0)	2 (2)	0 (0)	0 (0)	1 (1)	3 (3)
W4548	5/14	1	4 (4)	5 (5)	20 (20)	4 (4)	0 (0)	0 (0)	33 (33)
W4546	5/12	1	16 (16)	0 (0)	3 (3)	0 (0)	0 (0)	3 (3)	22 (22)
W4058	8/6—9/13	14	95 (81)	283 (190)	613 (426)	243 (137)	13 (9)	0 (0)	1247 (843)
W4056	8/2—9/13	17	1689 (1167)	343 (160)	1620 (1020)	565 (413)	12 (12)	0 (0)	4233 (2772)
W4046	5/17	1	0 (0)	2 (2)	13 (13)	0 (0)	0 (0)	4 (4)	19 (19)
W4042	4/18	1	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
W3556	8/2—9/5	2	43 (37)	134 (88)	698 (494)	12 (12)	0 (0)	0 (0)	887 (631)
W3554	7/30—8/1	6	96 (46)	6 (0)	29 (8)	75 (28)	3 (2)	0 (0)	209 (84)
W3552	7/29	3	4 (0)	4 (0)	4 (2)	0 (0)	0 (0)	3 (0)	15 (2)
W3548	5/8	1	0 (0)	57 (57)	33 (33)	1 (1)	0 (0)	0 (0)	91 (91)
W3050	7/26	2	6 (4)	52 (16)	33 (10)	12 (5)	1 (1)	0 (0)	104 (36)
W3048	7/22—9/24	4	7 (1)	49 (2)	55 (22)	551 (308)	2 (0)	0 (0)	667 (333)
W3046	7/21	1	1 (1)	0 (0)	4 (4)	123 (109)	1 (0)	0 (0)	129 (114)
W2548	9/25	1	0 (0)	4 (0)	0 (0)	17 (0)	0 (0)	1 (0)	22 (0)
W2546	7/21	1	3 (3)	2 (1)	9 (9)	64 (33)	11 (2)	0 (0)	89 (48)
Purse seine totals (24 areas)									
	6/7—9/25	150	7157 (6018)	6362 (2608)	6003 (3764)	1913 (1187)	146 (95)	15 (11)	21596 (13683)
Totals, longline and purse seine combined									
	4/12—9/25	274	10353 (6840)	7101 (3152)	7574 (4854)	2059 (1291)	152 (96)	170 (130)	27409 (16363)

and southeastern Alaska. Subsequent commercial catches of pink salmon in all Gulf coastal areas were considerably less than in 1963. Sizes of pink salmon (21–23 fish per case) in the Kodiak Island area were very close to the size indicated by length and weight data from catches in the north-central Gulf in June and early July.

Coho salmon and steelhead trout were caught in small numbers south of lat. 50°N in the spring, and occurred farther north as the season progressed. The longline gear took very few chinook salmon.

Few seine sets were made in the southern Gulf, due to unfavorable fishing weather, but on May 8 in area W3548 a single seine set took 57 chum salmon, of which seven were 2-year-old fish between 30 and 40 cm long. The longline set at the same location took 23 chum salmon, all older than two years and over 40 cm long; this size indicates the selectivity of longline gear for large fish.

Tag returns from releases in the Gulf of Alaska are illustrated in Figures 2 to 7.

Returns of sockeye salmon by 2° × 5° release areas are shown by month of release in 14 major recovery areas in Figure 2. This figure indicates rather patchy distribution of stocks in the Gulf, but is more nearly adequate when Canadian and Japanese data are considered. As mentioned earlier, most sockeye salmon from Gulf longline sampling in 1965 were preserved for meristic and parasite studies, the results of which will be reported by Canada. Figure 2 does show, however, a mixture of many stocks in the northern Gulf, and mainly the southern stocks in the southern Gulf. The determination of maturity for calculation of the 10.8 percent rate of return was based on lengths, and date and location of sampling.

The few tag recoveries of chum salmon (Fig. 3) showed a distribution similar to that of earlier years. Determination of maturity was by the same means as for sockeye salmon. The relatively low rate of return (3.6 percent) is typical for this species.

Tag returns of pink salmon from Gulf of Alaska releases (Fig. 4) were also sparse, but showed a mixing

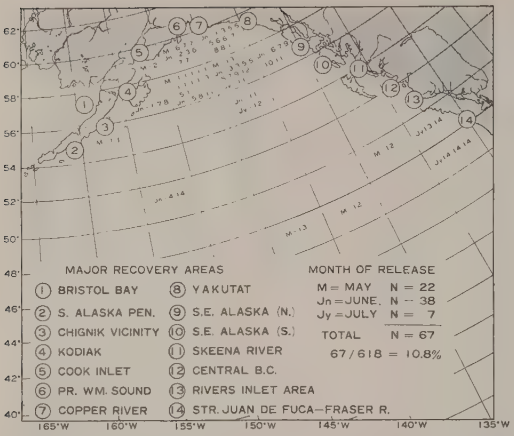

MAJOR RECOVERY AREAS
① BRISTOL BAY
② S. ALASKA PEN.
③ CHIGNIK VICINITY
④ KODIAK
⑤ COOK INLET
⑥ PR. WM. SOUND
⑦ COPPER RIVER
⑧ YAKUTAT
⑨ S.E. ALASKA (N.)
⑩ S.E. ALASKA (S.)
⑪ SKEENA RIVER
⑫ CENTRAL B.C.
⑬ RIVERS INLET AREA
⑭ STR. JUAN DE FUCA—FRASER R.
MONTH OF RELEASE
M = MAY N = 22
Jn = JUNE N = 38
Jy = JULY N = 7
TOTAL N = 67
67/618 = 10.8%
62° 60° 58° 56° 54° 52° 50° 48° 46° 44° 42° 40°
165°W 160°W 155°W 150°W 145°W 140°W 135°W

FIGURE 2. Recovery distribution of mature sockeye salmon tagged in the Gulf of Alaska in 1965 by 2° × 5° release areas and by month of tagging.

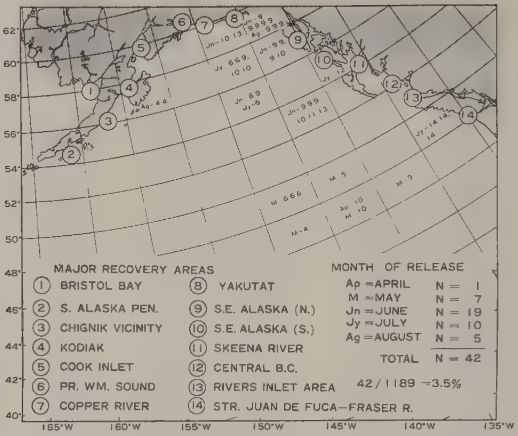

MAJOR RECOVERY AREAS
① BRISTOL BAY
② S. ALASKA PEN.
③ CHIGNIK VICINITY
④ KODIAK
⑤ COOK INLET
⑥ PR. WM. SOUND
⑦ COPPER RIVER
⑧ YAKUTAT
⑨ S.E. ALASKA (N.)
⑩ S.E. ALASKA (S.)
⑪ SKEENA RIVER
⑫ CENTRAL B.C.
⑬ RIVERS INLET AREA
⑭ STR. JUAN DE FUCA—FRASER R.
MONTH OF RELEASE
Ap = APRIL N = 1
M = MAY N = 7
Jn = JUNE N = 19
Jy = JULY N = 10
Ag = AUGUST N = 5
TOTAL N = 42
42/1189 = 3.5%
62° 60° 58° 56° 54° 52° 50° 48° 46° 44° 42° 40°
165°W 160°W 155°W 150°W 145°W 140°W 135°W

FIGURE 4. Recovery distribution of pink salmon tagged in the Gulf of Alaska in 1965 by 2° × 5° release areas and by month of tagging.

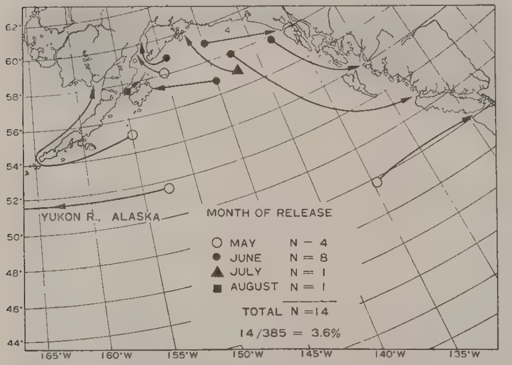

YUKON R., ALASKA
MONTH OF RELEASE
○ MAY N = 4
● JUNE N = 8
▲ JULY N = 1
■ AUGUST N = 1
TOTAL N = 14
14/385 = 3.6%
4
62° 60° 58° 56° 54° 52° 50° 48° 46° 44°
165°W 160°W 155°W 150°W 145°W 140°W 135°W

FIGURE 3. Recovery distribution of mature chum salmon tagged in the Gulf of Alaska in 1965 by month of tagging.

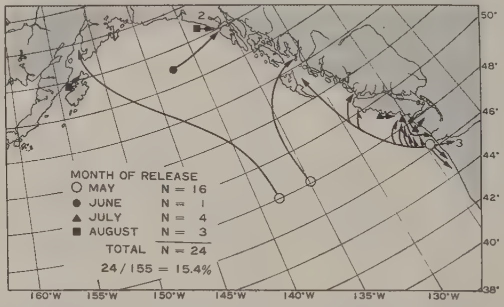

MONTH OF RELEASE
○ MAY N = 16
● JUNE N = 1
▲ JULY N = 4
■ AUGUST N = 3
TOTAL N = 24
24/155 = 15.4%
2
3
50° 48° 46° 44° 42° 40° 38°
160°W 155°W 150°W 145°W 140°W 135°W 130°W

FIGURE 5. Recovery distribution of coho salmon tagged in the Gulf of Alaska in 1965 by month of tagging.

of stocks similar to that of earlier years. In spite of widespread tagging early in the season, returns from the Puget Sound-Fraser River area came only from July releases near the coast. Perhaps the sampled fish examined by Canada will shed some light on the distribution of these stocks. The 3.5 percent total rate of return is typical for pink salmon. The fish caught by longline and released between April 12 and July 15 yielded 3.0 percent returns (33/1086). Seine-caught fish released along the coast between July 21 and September 25 yielded 8.7 percent returns (9/103).

The most significant feature of the tagging of coho salmon (Fig. 5) was the high rate of return from 30 longline-caught fish tagged 16 miles off the mouth of the Columbia River on May 2; 14 (46.7 percent) were recovered. Recoveries ranged from central Oregon to central British Columbia, and were made from May 3 through October 20. Only three were from the Columbia River. Excluding the May 2 experiment, 10 of 125 releases were recovered, or 8.0 percent. The results suggest a very high exploitation rate on coho salmon stocks that remain inshore.

Figures 6 and 7 show the returns in 1964 and 1965, respectively, of coho salmon (caught by purse seines) tagged as fingerlings in 1964 during their first summer at sea. The eight returns in 1964 are included in this report because five recovered in the Strait of Juan de Fuca (Fig. 6) were erroneously recorded as Fraser River recoveries in INPFC Document 780 (IBM table of U.S. tag returns in 1964). The distribution of returns no doubt was influenced by the distribution of fishing effort in the late fall of 1964, but the results indicate that the coho salmon fingerlings in the western Strait of Juan de Fuca do not necessarily proceed out

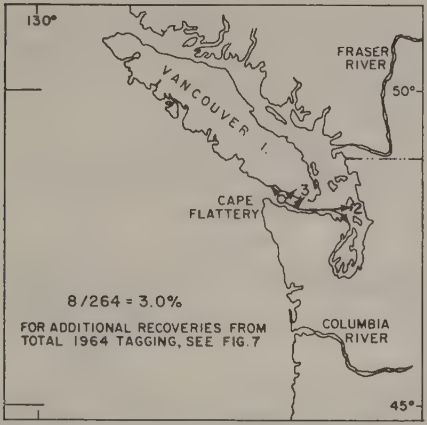

130°
FRASER RIVER
50°
VANCOUVER I.
3
2
CAPE FLATTERY
8/264 = 3.0%
FOR ADDITIONAL RECOVERIES FROM TOTAL 1964 TAGGING, SEE FIG. 7
COLUMBIA RIVER
45°

Figure 6. Distribution of eight recoveries in 1964 of coho salmon fingerlings (first summer at sea) tagged near Cape Flattery on September 24, 1964. All were caught in the Strait of Juan de Fuca.

to sea. Three migrated eastward as far as the entrance to Puget Sound. Another important feature of these eight returns is that all were tagged with the 3/4″ diameter red and white discs used on larger salmon. Of the 264 fish released, 132 were tagged with discs, and 132 with darts. Eight discs (6.1 percent) were recovered in 1964, and two (1.5 percent) in 1965—a total of 7.6 percent. The 132 darts yielded no returns in 1964, and only one in 1965 (0.8 percent). Such results speak well for discs on fish that average only 27 cm long. The mean size of the dart-tagged fish was 26 cm, but such a slight difference could hardly account for the much poorer return. Undoubtedly the disc-tagged fish recovered in 1964 were held in the nets by entanglement of the discs in the web (seven were recovered in gillnets and one in a purse seine).

Every 1965 return from the 1964 releases (Fig. 7) was from a point south of the release locations; the fish apparently had migrated northward upon entering the sea. Six bore dart tags and two carried discs.

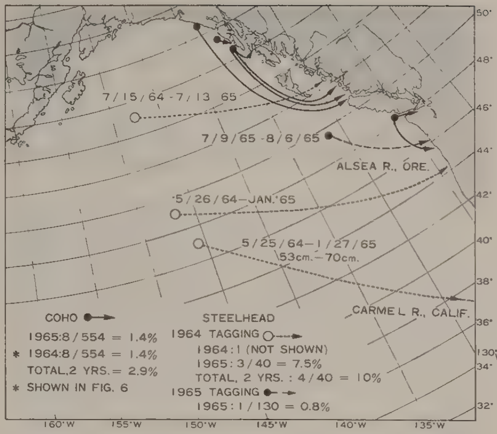

7/15/64-7/13 65
7/9/65-8/6/65
ALSEA R., ORE.
5/26/64—JAN.'65
5/25/64—1/27/65
53cm.—70cm.
CARMEL R., CALIF.
COHO ●→
1965:8/554 = 1.4%
* 1964:8/554 = 1.4%
TOTAL, 2 YRS. = 2.9%
* SHOWN IN FIG. 6
STEELHEAD
1964 TAGGING ○---→
1964:1 (NOT SHOWN)
1965: 3/40 = 7.5%
TOTAL, 2 YRS. : 4/40 = 10%
1965 TAGGING ●- →
1965: 1/130 = 0.8%
50°
48°
46°
44°
42°
40°
38°
36°
130°W
34°
32°
160°W
155°W
150°W
145°W
140°W
135°W

Figure 7. Recovery distribution of coho fingerlings tagged in 1964 and recovered in 1965. (Recoveries in 1964 are shown in Fig. 6.) Steelhead trout tagged in 1964 and 1965 and recovered in 1965 are also shown.

Table 2 summarizes returns from the two types of tags.

Figure 7 also shows data for three steelhead released in 1964 and recovered in 1965, and one tagged and recovered in 1965. All but the one in the Queen Charlotte Sound area were recovered in rivers by sport fishermen.

Central Aleutian Purse-seine Indexing

The main objective of the central Aleutian work was to obtain an index of the abundance and age composition of immature sockeye salmon in the central Aleutian area upon which to base a forecast for the 1966 Bristol Bay run. Secondary objectives were to observe movements of individual salmon in the vicinity of release by means of sonic tags, and to study feeding habits of immature salmon in this important area. Numbers of salmon caught and tagged in purse-seine fishing (area 8050) through August 17 are listed in Table 1.

Table 2. Recoveries of coho salmon tagged during their first summer at sea, 1964.

Type of tag	Number tagged	Number recovered			Percentage recovered		
		1964	1965	Total	1964	1965	Total
All 1964 experiments							
Dart	368	0	6	6	0.0	1.6	1.6
Disc	186	8	2	10	4.3	1.1	5.4
Total	554	8	8	16	1.4	1.4	2.9
Set C120 only (Strait of Juan de Fuca, 9/24/64)							
Dart	132	0	1	1	0.0	0.8	0.8
Disc	132	8	2	10	6.1	1.5	7.6
Total	264	8	3	11	3.0	1.1	4.2

The vessel *Commander* seined south of Adak from June 10 to August 17. A good series of index seine sets was obtained and catches indicate a good run to Bristol Bay in 1966. The age composition was about evenly divided between 1- and 2-winter-at-sea fish. Most immature 2-winter-at-sea fish had two freshwater annuli, similar to the mature fish at Bristol Bay in the 1965 run.

Over 700 mature sockeye salmon were also tagged in the Adak area. Since the peak had probably passed by the time (June 10) that operations began, these salmon undoubtedly were from the last half of the spawning run. While en route to Adak the *Commander* also tagged one day (June 7) south of Unalaska Island alongside the *Yaquina* (chartered by the Bureau of Commercial Fisheries) to support tagging studies described in the section, "Ocean Mortality and Growth".

Most of the chum salmon caught in the Adak area were immature fish not due to return in 1965. The average catch was somewhat less than in 1964 when 65 sets yielded 6,809 chum salmon, as against 5,158 in 67 sets in 1965 for comparable time periods.

Pink salmon were more abundant than in even-numbered years, but the catch was not large for an odd-numbered year. Average catch per set from June 10 through July 4 was 30 as against 55 in 1963 and 101 in 1961 for comparable time periods.

Catches of coho salmon were considerably larger than in recent years. The catch of coho salmon was 95 in 1965 as compared with seven in 1964, 43 in 1963, and 20 in 1962 for comparable effort. It is hoped that tag returns will be sufficient to indicate the continent of origin of these fish.

The recovery distributions of salmon tagged in the Aleutian area are shown in Figures 8 to 12.

Mature sockeye salmon (Fig. 8) tagged in the central Aleutian area between June 10 and 19 yielded

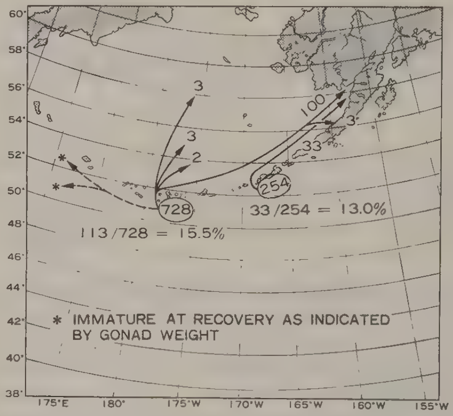
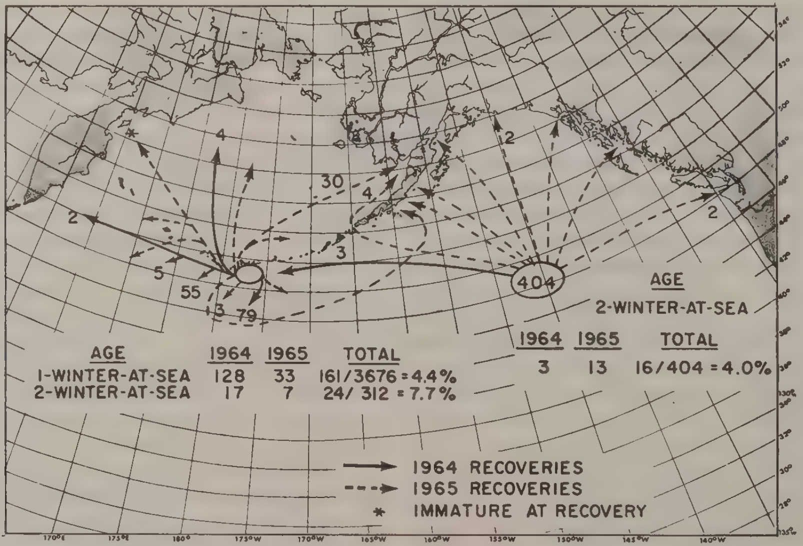

60°
58°
56°
54°
52°
50°
48°
46°
44°
42°
40°
38°
175°E
180°
175°W
170°W
165°W
160°W
155°W
3
100
3
3
2
33
254
728
33/254 = 13.0%
113/728 = 15.5%
* IMMATURE AT RECOVERY AS INDICATED BY GONAD WEIGHT

FIGURE 8. Recovery distribution of sockeye salmon tagged in the Aleutian area in 1965.


4
2
30
4
2
2
5
3
55
3
79
404
1964 RECOVERIES
1965 RECOVERIES
* IMMATURE AT RECOVERY
170°E
175°E
180°
175°W
170°W
165°W
160°W
155°W
150°W
145°W
140°W

AGE	1964	1965	TOTAL
1-WINTER-AT-SEA	128	33	161/3676 = 4.4%
2-WINTER-AT-SEA	17	7	24/312 = 7.7%

AGE 2-WINTER-AT-SEA 1964	1965	TOTAL
3	13	16/404 = 4.0%

FIGURE 9. Recovery distribution of sockeye salmon tagged as immature fish in 1964 and recovered in 1964 and 1965.

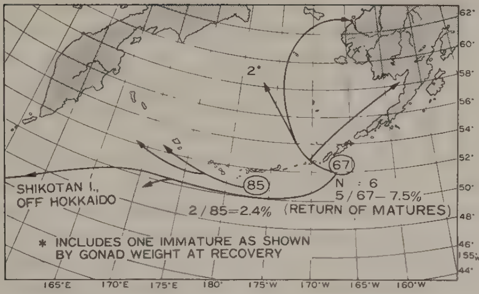


Figure 10. Recovery distribution of chum salmon tagged in the Aleutian area in 1965.

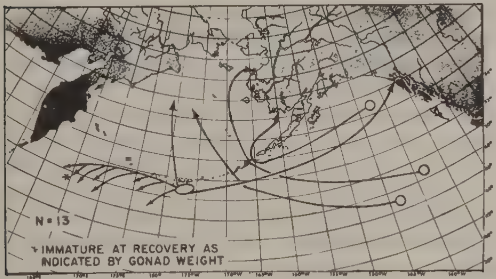


Figure 11. Recovery distribution of chum salmon tagged in 1964 and recovered in 1965.

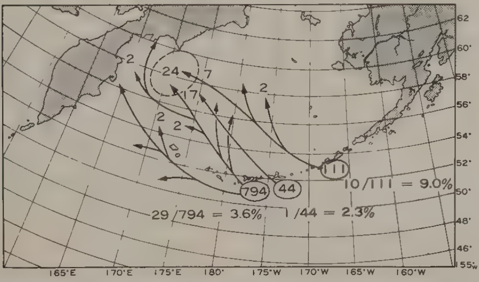


Figure 12. Recovery distribution of pink salmon tagged in the Aleutian area in 1965.

103 returns from Bristol Bay and eight from the high seas at intermediate points in the Bering Sea. The distribution is typical of earlier years' results. The two recovered at sea near Attu were immature fish. Such migrations are typical of immature sockeye salmon which characteristically migrate westward through the central Aleutians; the fish which have spent two winters at sea are frequently intercepted by the mothership fleet, particularly in years when the fleet returns to the Aleutian area in July and August. The rate of return (15.6 percent) was slightly better than in any previous year's tagging in the central Aleutians. The two immature sockeye are included, since by length and date of tagging (49.0 cm, 6/10; and 46.5 cm, 6/13) they fall among those classified as mature at tagging. The mean length of 45 cm, which served to separate mature and immature fish in this study, undoubtedly misclassified some of each category.

The 254 mature sockeye salmon tagged south of the eastern Aleutians on June 7 and 23 yielded 33 returns, all from Bristol Bay—a typical distribution from releases in this area. Total return was 13.0 percent. The 90 tagged from longline gear yielded nine returns or 10.0 percent, and the 164 tagged from purse seines yielded 24 returns or 14.6 percent, similar to the rate observed at Adak.

The returns from sockeye salmon tagged as immature fish in 1964 are shown in Figure 9 for both Aleutian area and Gulf of Alaska releases. The 3,988 fish tagged south of Adak were released between June 15 and August 15; they may be considered representative of the major mass of immature fish passing this point in 1964. One-winter-at-sea fish greatly predominated in the seine catches as expected following the large outmigration from Bristol Bay rivers in 1963. The 404 releases in the Gulf of Alaska were made during May, when the center of abundance of immature sockeye salmon appeared to be in the release area illustrated in Figure 9. Only 2-winter-at-sea fish are considered, because longline gear does not take the 1-winter-at-sea fish in true proportion to their relative numbers, and gear injury to the smaller fish greatly reduces survival.

The releases of immature sockeye salmon off Adak yielded 185 returns—145 in 1964, from the Japanese mothership fleet, and 40 in 1965, of which nine were from the high seas, one from the Shumagin Islands, and 30 from Bristol Bay. Rates of return were unusually high (4.4 percent of 1-winter-at-sea fish and 7.7 percent of 2-winter-at-sea fish). This high rate resulted from the heavy interception at sea in 1964 in which year the Japanese fleet made an unprecedented return to the central Aleutian area in late July and early August when immature sockeye salmon were abundant. The interceptions on the high seas in 1964 indicated a westward migration south of the Aleutians extending as far as long. 164°E, and also some dispersion far to the northwest in the Bering Sea. The following year, returns from the high seas were widely distributed along the various approaches to Bristol Bay. The one fish recovered in 1965 near East Kamchatka was still immature at recovery; some Bristol Bay sockeye may remain far to the west while feeding.

Tags from the Soviet Union had not yet been received at the time of writing but few, if any, are expected since in 10 years of tagging south of Adak there has been only one Asian recovery of a sockeye salmon, whereas chum and pink salmon tagged at the same time have yielded numerous Asian recoveries each year. The one recovery from the Shumagin Islands was most likely destined for Bristol Bay, since many fish caught in the Shumagin Islands area are moving westward as evidenced by seine fishing and by tag returns from coastal experiments. In fact this recovery is probably typical of part of the immature sockeye from the Adak area ; they seem to make a return migration to the Gulf of Alaska during the winter following their migration westward. As mentioned, a large number of mature sockeye tagged in the Gulf of Alaska in 1965 were recovered in Bristol Bay. Figure 9 indicates then, that the mass of immature sockeye passing Adak in 1964 was of Bristol Bay origin, with little admixture of Gulf of Alaskan or of Asian stocks.

By contrast, the 404 immature sockeye salmon tagged in the central Gulf of Alaska were obviously a mixture of all major Gulf stocks, plus Bristol Bay stocks. The three intercepted at sea near Adak in the year of release probably indicate the migration of only the Bristol Bay component of the mixture. If the mixture had migrated to Adak intact, then the Adak releases should have yielded Gulf of Alaska returns. Thus, stocks of salmon originating in various coastal areas may at times be mixed during their ocean-feeding migration, but nevertheless have differing migration. The Gulf of Alaska component of fish released in the Gulf apparently followed a more restricted, but unknown migratory path than did the Bristol Bay component. It may not be said that Gulf of Alaska sockeye do not migrate to the Aleutian area, since in 10 years, eight Gulf fish have been returned from central Aleutian releases a year or more after tagging as against 211 from Bristol Bay or the high seas.

Two returns were obtained in 1965 of sockeye salmon tagged as immature fish in 1963 ; both were fish which had spent one winter at sea at release. One was tagged at Adak and recovered in Bristol Bay ; the other was tagged in the central Gulf of Alaska (lat. 48°N and long. 145°W) and recovered in Cook Inlet. The latter fish was tagged with a plastic dart tag.

The distribution of recoveries of chum salmon tagged in the Aleutian area (Fig. 10) was typical of earlier years' results. The two high seas returns from the 85 mature fish released south of Adak were apparently destined for Asia. It is possible that coastal returns will be received from the Soviet Union. Releases in the eastern Aleutians indicated both American and Asian stocks. The high seas recovery classed as an immature fish on the basis of gonad size at recovery, was also classified as immature on the basis of length (41.5 cm) at release.

The recovery of chum salmon tagged as immature fish in 1964 and recovered in 1965 (Fig. 11) is also similar to that of previous years. The Adak releases yielded nine returns from the high seas, apparently destined for Asia, and one from southeastern Alaska. One high seas return was still immature at recovery, and two more were borderline according to gonad weights.

Distribution of pink salmon (Fig. 12) was typical of this species in an odd-numbered year. From all points of release, the high seas recoveries were on a path toward the Karaginski region of East Kamchatka. The one coastal recovery at Olyutorski Bay was received directly from an individual fisherman. Tags expected from the Soviet fisheries agency have not yet been received for 1964 or 1965. The variation in rate of return from the several release areas is probably due to the timing and distribution of the high seas fleet relative to the timing and migratory path of the fish released.

Behavior Studies by Means of Sonic Tags

Sonic tags, which were tested briefly in 1964 in a protected harbor, were employed this year in preliminary experiments to study in detail the movements of salmon in the vicinity of tagging in the open sea. Objectives were : (1) to study movements immediately after tagging. (2) To study actual rates of migration. (3) To check on the westward migration in the central Aleutian area, as indicated by the purse-seine fishing. (4) To find which passes are used in entering the Bering Sea and the manner and speed of negotiating the passes.

The tags were of the type developed by the Bureau of Commercial Fisheries Fish-Passage Research Program for study of migrations in the Columbia River (Trefethen, 1963). The tags were contained in streamlined plastic cylinders, 14 mm by 59 mm, and were attached by a plastic pin through the dorsal musculature just posterior to the dorsal fin. Battery life was sufficient to emit an interrupted signal about 100 hours. The receiving unit was carried in a skiff ; the underwater receiver was on the end of a hand-held aluminum probe six feet long. Effective receiving range was about 300–400 yards. This range was determined by tracking fish with a small float attached by a light monofilament leader 20 feet long.

Four salmon were tagged with sonic tags between 9 and 12 miles south of Adak as follows:

Date	*Species*	*Length (cm)*	*Remarks*
6/30	Sockeye	50.0	Mature
6/30	Chum	43.0	Probably immature
7/12	Chum	54.0	Maturity unknown
8/8	Chum	54.0	Maturity unknown

Contact with the two salmon tagged on June 30 was lost after short periods of tracking. Both moved rapidly and erratically when first released. Loss of contact may have been due to the masking of the signal by tide rips, and to inexperience with the equipment.

The chum salmon tagged on July 12 was followed 9⅔ hours over a distance of 12 miles. The net direction of travel was south by west. Although net rate of travel was about 1.25 miles per hour, the fish alternately moved rapidly and remained stationary.

The chum salmon tagged on August 8 was tracked 17 hours (1045–0330) over a distance of 23 miles. The net direction of travel was also south by west, at a net rate of 1.35 miles per hour. Several times the fish remained relatively stationary, once during the night for 80 minutes. Contact was lost while the fish was moving rapidly during the night. The search to regain contact was abandoned after 1½ hours.

Conclusions can hardly be drawn on the basis of only two fish tracked over such short periods, but the net rates of travel were consistent with the 25 to 30 miles per day commonly observed from tag-recovery data over a number of days. The two specimens obviously did not linger in the area of tagging but it is not known how much of their movement was due to currents and how much to swimming. At times the following skiff had to operate its motor continuously to maintain contact, indicating active swimming. At such times, direction of travel was not consistent. The effect of the tag is also unknown.

A thorough study of movements by means of sonic tags to answer the objectives stated earlier would require considerable time. A simultaneous study of the currents would also be helpful. Long-term tracking would require a covered skiff with the probe mounted in a through-hull unit. Problems still to be contended with are the effects of tide rips and surface reflection on the tag signal.

Seining of Fingerling Salmon in the Gulf of Alaska

A fine-meshed purse seine was used to study the distribution, abundance, migrations, length, and growth of fingerling salmon of all species during their first summer at sea. Secondary objectives were (1) to test two types of tags for young salmon, (2) to study feeding habits of salmon fingerlings during early ocean residence, and (3) to conduct initial studies on the effects of handling and tagging injuries, particularly scaling. The vessel *Storm* carried out these operations from July 20 through September 25. Table 1 lists catch and tagging totals by statistical area.

Outstanding observations are as follows:

1. Catches confirmed the 1964 observation that the fish are primarily in a belt within 20 miles of shore and move predominantly northward along the Washington, British Columbia, and southeastern Alaska coasts.

2. Between Cape Flattery and Lituya Bay (lats. 48° to 59°N) the catches of salmon in their first summer at sea were notably less than in 1964.

3. Chinook salmon, which were practically absent from catches in 1964, occurred frequently though in small numbers in all areas of fishing in 1965.

4. The sampling which terminated at Lituya Bay (lat. 58½°N) in 1964 was extended in 1965 around the northern periphery of the Gulf of Alaska to Kodiak Island. Salmon fingerlings were found to be moving westward in the northern parts of the Gulf and southwestward through Shelikof Strait in the Kodiak area. Time did not permit the making of sets in opposed directions or determination of the width of the band of fish in the northern Gulf and near Kodiak. Catches were substantial near Middleton Island; this indicates fingerling salmon are present 50 miles offshore. It is likely that the greater offshore distribution of fingerlings is associated with the wider continental shelf in this area.

Two new types of tags were tested on salmon fingerlings in 1965: (1) a modified plastic dart tag held in the body of the fish by a knot rather than by a nylon barb; and (2) the Swedish dangler-type tag (Carlin, 1955) attached through the dorsal musculature of the body by two fine stainless steel wires. Comparative tagging was sufficient to give results in 1966 that should indicate the relative merits of the two tags.

Returns in 1965 by species, of plastic dart tags placed in 1964, were as follows:

	Pink	*Coho*
Number returned and number tagged	0/1018	6/368
Percentage returned	0	1.6

Only pink and coho salmon would be expected to mature and to yield returns in 1965; results on the other species will not be seen until 1966 and 1967. The lack of pink salmon returns, however, suggests that the dart tags are unsatisfactory, at least on fingerlings in the 10–20 cm size range. The greater returns from tagging of coho salmon may have been due to their larger size (25 cm) at tagging and consequently better retention of tags.

PRELIMINARY STUDIES ON THE EFFECTS OF LOSS OF SCALES

Since loss of scales has already been shown to affect the tag-return rate of small salmon significantly, preliminary experiments were carried out this summer to measure the short-term survival and the physiological changes in " descaled " fish. By removing scales to various degrees and holding the fish in a 1000-gallon deck tank, it was learned that 30–50 percent descaling was the upper limit of scale loss if survival is to be reasonably good in small (first-summer-at-sea) salmon. Loss of more than 50 percent of the scales produced skin inflammation, dilution of blood constituents, and decline of general muscular vigor which were usually fatal within 3–18 hours. Scales were removed also from adult fish ; although serious skin damage in the form of whitened, blistered areas was conspicuous, the fish were still alive and active at the end of three days.

These experiments emphasize the continuing need to minimize the injury to small fish while they are being caught and tagged and not to assume that tagged fish behave and survive the same as untagged fish. Further experiments are planned on the basic physiology of tagging, anesthetizing, and " descaling " fish to develop methods to minimize injury and improve survival of tagged fish.

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DISTRIBUTION AND ABUNDANCE OF SALMON

by R.R. French, D.R. Craddock, and J.R. Dunn

Research cruises were made on the high seas in the winter, spring, and fall of 1965. The winter cruise, a continuation of high seas winter research begun by the United States in 1962, was directed toward determination of the distribution, movements, and relative abundance of salmon in different areas during February and March. Vertical distribution of the salmon was also investigated by fishing gillnets at selected depths. The spring cruise was made primarily to determine " dropout " rates (that is, numbers of salmon caught by the gillnets but not landed), and also to study the distribution of sockeye salmon migrating to Bristol Bay. The cruise covered areas in the migratory path of the salmon, south of Unalaska Island and north of the Alaska Peninsula, during June and early July. The fall cruise, a joint fishing-oceanography study, was made to determine distribution and abundance of salmon on north-south and east-west lines relative to the position of oceanographic fronts and the location of the Alaskan Stream. Fishing took place in the central Aleutians south of Attu during October and November.

This report briefly summarizes the data obtained during the winter, spring, and fall cruises and presents preliminary analyses of data collected in the dropout study.

WINTER CRUISE

Locations of stations occupied in the northwest Pacific Ocean by the RV *George B. Kelez* in February and March are shown in Figure 13.

The standard gillnet string consisted of 26 braided nylon nets—14 of 4½″ mesh, three each of 5¼″ and 3¼″, two of 2½″, and four of 2″ mesh. For the studies of vertical distribution, additional nets were attached below two of the 4½″ and two of the 2″ mesh nets. The sunken nets fished at depths of 24 to 48 feet and 48 to 72 feet.

Catch records from the winter cruise are listed in Table 3. In addition to the salmonids, nine salmon sharks (*Lamna ditropis*) were caught.

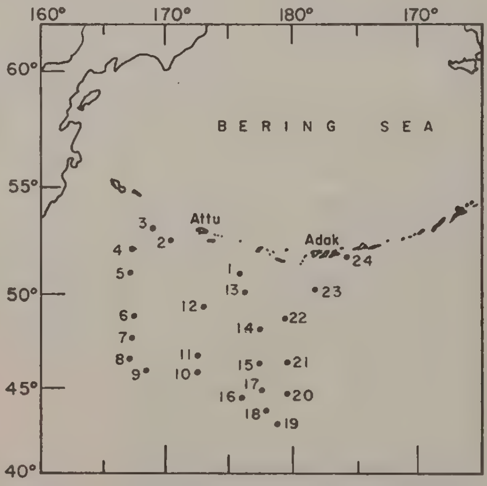

FIGURE 13. Location of fishing stations of the RV *George B. Kelez*, February 15-March 19, 1965.

TABLE 3. Salmon and steelhead catches, RV *George B. Kelez*, winter cruise, 1965.

Set no.	Date	Position		Surface temp. (°C)	Number of shackles	Species					
		Lat. (N)	Long.			Sockeye	Chum	Pink	Coho	Steelhead	Total
1	2/15	51—00	176—01 E	3.0	34[2]	67	—	—	—	—	67
2	2/17	52—16	170—33 E	2.8	34[2]	1	—	—	—	—	1
3[1]	2/19	53—05	169—07 E	2.2	20	16	—	—	—	—	16
4	2/20	52—22	167—32 E	1.8	20	2	—	—	—	—	2
5	2/21	50—59	167—26 E	1.8	24	6	—	—	—	—	6
6	2/22	49—12	167—18 E	1.6	24	42	—	—	—	—	42
7	2/23	48—14	167—19 E	2.2	24	11	—	—	—	—	11
8	2/24	47—08	167—07 E	2.2	24	21	—	—	—	—	21
9	2/26	46—04	168—40 E	2.4	24	19	1	—	—	—	20
10	2/28	45—59	172—50 E	4.6	24	6	—	—	—	—	6
11	3/1	47—12	172—39 E	2.6	24	34	—	—	—	—	34
12	3/2	49—34	173—10 E	2.6	24	15	—	—	—	—	15
13	3/3	50—02	176—15 E	3.1	24	19	—	—	—	—	19
14	3/9	48—11	177—17 E	2.8	24	25	—	—	—	—	25
15	3/10	46—43	176—10 E	4.0	36[2]	94	6	—	—	—	100
16	3/11	44—57	176—10 E	5.3	24	—	1	—	—	—	1
17	3/12	45—00	177—58 E	4.7	24	2	10	—	—	—	12
18	3/13	43—55	177—51 E	6.9	24	—	2	—	10	—	12
19	3/14	42—50	179—00 E	6.9	24	—	1	—	—	—	1
20	3/15	44—54	179—24 E	7.1	24	—	4	3	9	1	17
21	3/16	46—40	179—30 E	3.7	36[2]	60	4	—	—	—	64
22	3/17	48—39	179—30 E	3.4	36[2]	14	6	—	—	—	20
23	3/18	50—18	178—12W	3.2	36[2]	73	7	—	—	—	80
24	3 19	51—32	176—25W	3.2	24	—	4	—	—	—	4
				Total		527	46	3	19	1	596

[1] Nets in the water for two nights.

[2] Includes eight shackles fished at depths below the surface nets.

Distribution and Relative Abundance

Sockeye salmon which had spent two, three, and four winters at sea were distributed throughout the area between longs. 178°W and 167°E (Fig. 14); concentrations were heaviest at stations nearest the Aleutian Island chain. Sockeye salmon were not caught at the station just south of Adak Island, and the lack of this species was noticeable at stations south of lat. 45°N. The 1-winter-at-sea fish were less widely distributed than the older sockeye salmon and were found principally in a band between lats. 46° and 47°N, between longs. 180° and 175°E. This winter cruise is the first in which we have taken 1-winter-at-sea fish in excess of 10 per 100 fathoms of gillnet.

Chum salmon were caught principally in the eastern part of the cruise area and, unlike the sockeye salmon, they were taken also at the southernmost stations. Chum salmon were relatively few; no 2- or 3-year-old fish were taken.

A few pink and coho salmon and steelhead were taken at two stations in the southeastern part of the cruise area, south of lat. 45°N, and between longs. 180° and 177°E. The catches in this area, in addition to these three species, included chum salmon but not sockeye salmon.

Length and Age Composition

Length frequencies, by number of winters at sea, of sockeye salmon are given in Figure 15. Overlap in the length frequencies of the 2- and 3-winter fish and of the 3- and 4-winter fish was pronounced. Among the older sockeye salmon, taken in 3¼″, 4½″, and 5¼″ mesh nets, approximately 53 percent were 2-winter fish, 45 percent were 3-winter fish, and two percent were 4-winter fish. Age 5_3 fish dominated among the 2-winter sockeye (88 percent); ages 5_2 and 6_3 were about equally represented among the 3-winter-at-sea fish. Among the 1-winter-at-sea sockeye salmon taken in the 2″ and 2½″ mesh nets, age 4_3 dominated (79 percent).

Distribution of the various age groups of sockeye salmon (Fig. 16) revealed that generally 3- and 4-winter sockeye were in greater abundance west of long. 170°E than to the east; 2-winter fish were more abundant east of long. 170°E. In the area west of long. 170°E, the age composition, excluding 1-

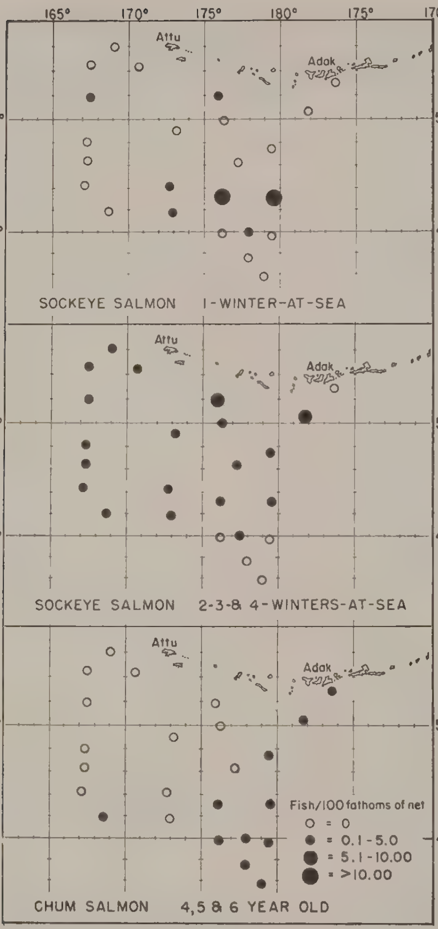

FIGURE 14. Relative abundance of sockeye and chum salmon, February-March 1965.

winter-at-sea fish, was seven percent 2-winter, 86 percent 3-winter, and seven percent 4-winter fish ; east of long. 170°E, the age composition, again excluding 1-winter-at-sea fish, was 70 percent 2-winter and 30 percent 3-winter fish. As mentioned previously, 1-winter-at-sea sockeye, ages 3_2 and 4_3, were concentrated between longs. 180° and 170°E and south of lat. 50°N.

Only three age groups of chum salmon appeared in the catches. Ages of 44 chum salmon were determined ; 33 were 4-year-olds, 10 were 5-year-olds, and one was a 6-year-old. No 3-year-old chum salmon were caught although 2-year-old fish had been present in the general area the previous September. Apparently, 2- and 3-year-old chum salmon were absent from the area of the northwest Pacific sampled in February and March 1965.

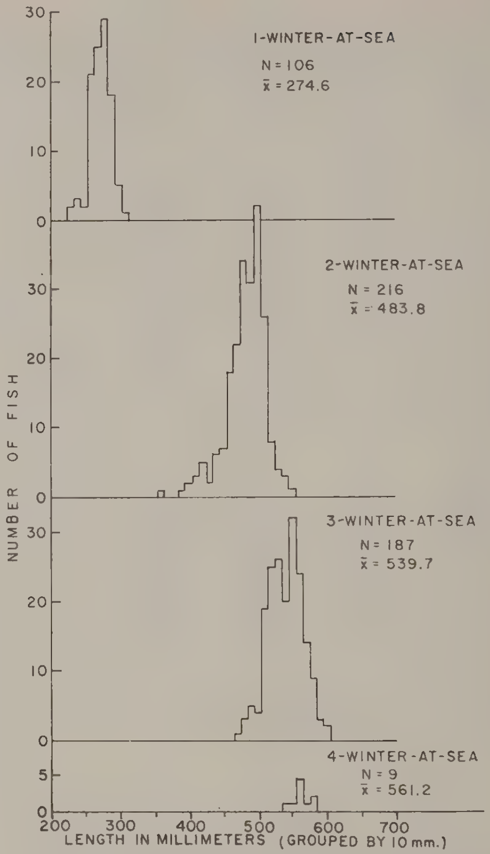

FIGURE 15. Length frequencies of sockeye salmon by number of winters at sea, winter cruise, RV *George B. Kelez*, 1965.

The three pink salmon caught during the winter cruise were 375, 378, and 399 mm long.

Coho salmon ranged from 343 mm to 459 mm long. Scales from 16 specimens showed that 13 were age 4_3 and three were age 3_2.

Maturity

Maturity of sockeye and chum salmon taken in February and March was determined by (1) serological methods (Ridgway, 1961) and (2) gonad-weight criteria (Ishida and Miyaguchi, 1958). Results of maturity determinations for female sockeye salmon are given in the section, " Serology ". It was found that 81 percent of the 2-winter-at-sea and 99 percent of the 3-winter sockeye salmon were maturing. Among the 2-winter males, for which gonad weights

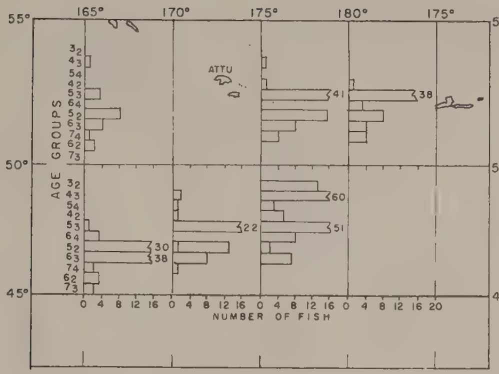

Figure 16. Distribution of sockeye salmon by age groups, winter cruise, RV *George B. Kelez*, 1965. (Catches weighted to six shackles of the 2- and 2½-inch mesh nets for 1-winter-at-sea fish and 18 shackles of 3¼-, 4½-, and 5¼-inch mesh nets for 2-, 3-, and 4-winter fish. Data combined for areas 5° lat. by 5° long.)

were obtained, 84 of 96 fish (88 percent) contained gonads weighing 1.5 g or more. If the remaining growing period from February-March to the inshore migratory period in June is considered, it is likely that these males would have matured. (Males with gonads weighing more than 2 g in May and June are considered to be maturing.) Ninety-four percent of the male 3-winter-at-sea sockeye salmon examined contained gonads that weighed 1.5 g or more. These fish were judged to be maturing.

Among 16 female chum salmon tested by serological methods, 15 were classed as maturing. Of 15 male chum salmon examined, 13 contained gonads that weighed 1.5 g or more. It is likely that these males were maturing.

We have concluded from these samples taken in the northwest Pacific in February and March that over 90 percent of the older salmon (3-winter-at-sea sockeye salmon and 4-, 5-, and 6-year-old chum salmon) would return to spawning streams the following summer and fall. We also concluded that at least 80 percent of the 2-winter-at-sea sockeye salmon were maturing and hence that no more than 20 percent of the fish would stay at sea for at least one more winter.

Vertical Distribution

Experimental fishing at depths from 24 to 48 feet and from 48 to 72 feet took relatively few fish during the night. In seven sets during which 56 shackles of gillnets were fished (28 shackles each at vertical ranges of 24–48 feet and 48–72 feet), only three salmon were caught—two sockeye salmon at 24–48 feet and one chum salmon at 48–72 feet. During these same seven sets, 28 surface nets (extending from the surface down to 24 feet) and fished directly over the sunken nets took 54 fish (52 sockeye and two chum salmon).

Environmental Relationships

The relationship between occurrence of salmon and subsurface temperatures is discussed under the section, " Oceanography ". An apparent relationship between surface temperatures and the distribution of salmon was indicated by the occurrence of pink and coho salmon and steelhead at two stations where surface temperatures were much higher than at other stations. At most stations, surface temperatures ranged from 1.8°C to 5.3°C (see Table 3). Two stations, however, with surface temperatures of 6.9°C and 7.1°C yielded our only catches of pink and coho salmon and steelhead.

Chum salmon occurred mainly in waters with surface temperatures greater than 3.2°C and, with one exception, were not taken in areas with temperatures less than 3.2°C. As we have found on past winter cruises, sockeye salmon were taken throughout the areas of low surface temperatures (4.7°C or colder) ; they were not taken in waters at four stations where temperatures were 5.3°C or higher.

Spring Cruise

Special gillnet strings of 5¼″ mesh nets were fished from the RV *George B. Kelez* and the chartered schooner *Paragon* (80 feet) during the spring to determine dropout rates. Longlines were fished from the *Kelez* on five occasions. Salmon catches of the two vessels are listed in Table 4.

Dropout Studies

Two experimental designs (developed by G. Hirschhorn, D. D. Worlund, and R. A. Fredin of the Laboratory's biometrics unit) were used to determine dropout rates of salmon. In the first design the nets were fished at night ; one unit of gear (four 50-fathom shackles of 5¼″ mesh gillnets per unit) was fished for six hours, a second unit for the first three hours, and a third unit for the second three hours (Fig. 17). This fishing was repeated over three different time periods during the night. The dropout rate was computed by comparing the catch of the 6-hour unit with those of similar units fished during the first and the second 3-hour intervals. In the second design four units of gillnets were set before daylight and fished for various lengths of time until noon. Additional units were fished concurrently as shown in Figure 18. In this design we expected that in the event fish did not enter gillnets set during daylight, the dropout rate could be measured directly by comparing catches of the gear units after various periods of time.

TABLE 4. Salmon catches, RV *George B. Kelez* and MV *Paragon*, spring cruise, 1965.

Set no.	Date	Position		Surface temp. (°C)	Gear[1]			Species				
		Lat. (N)	Long. (W)		Kind	Number	Shackle hours	Sockeye	Chum	Pink	Chinook	Total
RV *George B. Kelez*												
1	6/6	53—23	166—00	5.5	GN	28	112	24	1	—	—	25
2	6/7	53—01	166—03	5.2	GN	28	112	242	10	—	—	252
3	6/8	53—06	166—00	5.0	GN	28	112	157	4	—	—	161
4	6/9	53—32	166—17	—	LL	20	—	15	—	—	—	15
5	6/10	53—30	166—19	5.5	LL	17	—	33	2	3	—	38
6	6/11	53—30	166—18	5.6	LL	20	—	132	3	4	—	139
7	6/12	53—30	166—19	—	LL	20	—	7	—	—	—	7
8	6/14	53—07	166—37	6.6	GN	28	108	268	8	2	—	278
9	6/15	52—55	167—43	6.4	GN	16	72	364	13	2	—	379
10[2]	6/17	53—13	166—20	6.8	GN	28	120	82	3	2	1	88
11	6/18	53—19	166—10	6.5	GN	12	48	9	—	—	—	9
12	6/21	55—30	164—00	6.4	GN	16	60	2	4	—	—	6
13	6/22	55—50	164—00	6.2	GN	28	112	183	24	—	—	207
14	6/23	56—10	162—31	5.5	GN	28	116	110	28	—	—	138
15	6/25	57—01	159—58	5.4	GN	28	116	366	40	—	1	407
16	6/26	57—23	159—24	—	LL	10	—	100	—	—	—	100
17[2]	6/27	57—21	159—22	5.0	GN	14	64	449	10	—	1	460
18	6/29	57—45	160—19	4.4	GN	14	42	20	6	—	—	26
19	6/30	57—30	159—00	4.5	GN	16	12	132	—	—	—	132
21	7/2	56—24	162—00	7.6	GN	10	40	186	21	—	2	209
				Total				2,881	177	13	5	3,076
MV *Paragon*												
1	6/1	53—43	160—44	5.0	GN	28	112	51	15	—	—	66
2	6/4	53—23	166—01	4.8	GN	28	24	29	15	—	—	44
3	6/7	53—20	165—52	5.8	GN	28	104	322	10	—	—	332
4	6/8	53—26	165—57	5.5	GN	20	80	488	14	—	—	502
5[2]	6/10	53—18	166—00	5.5	GN	28	120	79	7	1	—	87
6[2]	6/11	53—07	166—28	5.5	GN	28	120	113	13	—	—	126
7	6/12	52—52	166—12	5.8	GN	28	116	52	1	—	—	53
8	6/14	53—15	166—38	6.2	GN	28	116	168	13	—	—	181
9	6/15	52—57	167—41	6.2	GN	28	108	374	16	—	—	390
10[2]	6/17	53—18	166—30	6.5	GN	28	120	17	1	—	—	18
11	6/18	53—16	166—15	6.7	GN	12	48	13	2	—	—	15
12	6/21	55—48	164—31	6.5	GN	28	108	147	8	—	—	155
13	6/22	55—55	164—00	6.3	GN	12	48	27	1	—	—	28
14	6/23	56—06	162—30	5.7	GN	28	112	395	54	—	—	449
15	6/25	56—37	161—30	5.9	GN	12	56	391	65	—	1	457
16[2]	6/26	56—43	161—30	6.8	GN	14	60	210	20	—	—	230
17	6/28	57—06	161—56	5.7	GN	14	58	25	12	—	—	37
18	6/29	56—47	161—25	6.5	GN	10	40	153	7	—	—	160
19	7/1	56—30	161—05	7.3	GN	14	58	49	5	—	—	54
20	7/2	56—17	162—00	8.3	GN	10	42	101	7	—	—	108
				Total				3,204	286	1	1	3,492

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[1] GN=shackles of gillnet, LL=skates of longline.

[2] Night-Day sets.

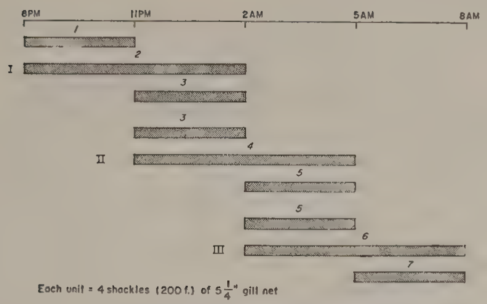

FIGURE 17. Fishing plan (nighttime) for study of dropout. Each unit of gear is identical; length of shaded area refers to fishing time.

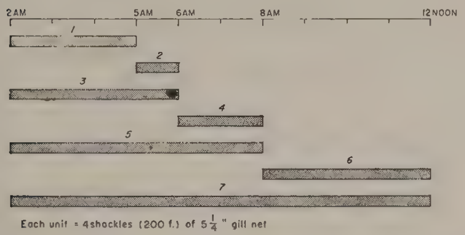

FIGURE 18. Fishing plan (night-day) for study of dropout. Each unit of gear is identical; length of shaded area refers to fishing time.

The night-fishing plan provided for the variation in catch attributable to fishing at different times of the night by setting standard units of gear (200 fathoms of $5\frac{1}{4}''$ mesh nets) to fish during four 3-hour time periods each night. These periods were 8–11 p.m., 11 p.m.–2 a.m., 2–5 a.m., and 5–8 a.m. In the North Pacific the largest catches were obtained between 8 and 11 p.m., and the smallest from 5 to 8 a.m. (Fig. 19). This distribution of catch by time periods was similar to that reported for the northwest Pacific area in the fall of 1964 (French, 1966).

The catch by time periods in the Bering Sea differed from that in the North Pacific in that the largest catches were between 11 p.m. and 2 a.m. and the smallest from 2 to 5 a.m. The most interesting difference between the two areas was in catches during daylight, from 5 to 8 a.m. (Sunrise occurred about 3:30 a.m. during this time of the year.) In the Bering Sea a substantial proportion of the fish were caught in the daylight period; in the North Pacific only 12 percent were caught during this same period.

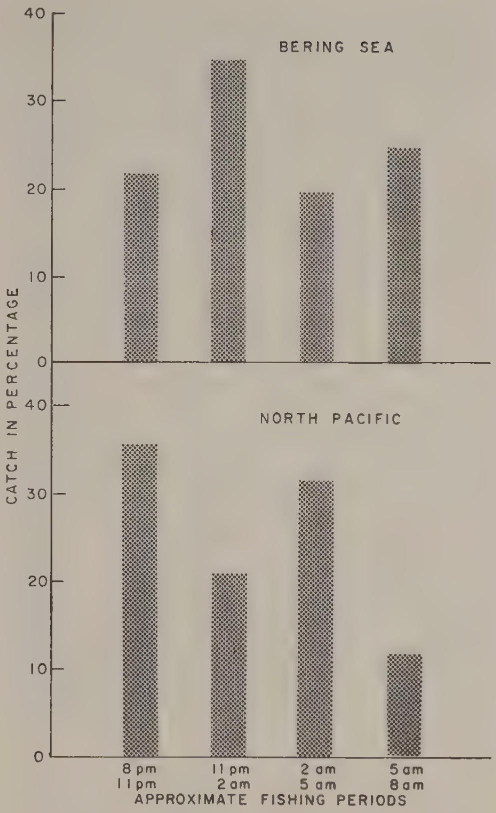

FIGURE 19. Percentage of total catch by 3-hour periods.

Loss of salmon from gillnets was estimated by regression analysis based on data from the catches taken in 52 time periods (a 6-hour catch versus two 3-hour catches, Figure 17). If we assume N_1 and N_2 are the numbers of fish available to the gillnets during the first and second 3-hour intervals, respectively, and that entry of fish into the nets occurs at the midpoint of the intervals, the expected catches of the three units (four 50-fathom shackles) are:

$$\hat{c}_1 = s_0\ u_1\ N_1 \quad \text{for the first 3-hour unit,}$$

$$\hat{c}_2 = s_0\ u_1\ N_2 \quad \text{for the second 3-hour unit,}$$

and $$\hat{C} = s_1\ s_0\ u_1\ N_1 + s_0\ u_2\ N_2 \quad \text{for the 6-hour unit}$$

where u_i is the fraction of N_i entering a unit during the i^{th} interval, s_0 is the fraction of $u_i\ N_i$ retained by the gillnets from the time of entry to the time of hauling, and s_1 is the fraction of $s_0\ u_1\ N_1$ retained by the 6-hour unit during the second 3-hour interval. Rewriting $\hat{C}$ in terms of $\hat{c}_1$ and $\hat{c}_2$ we have,

$$\hat{C} = s_1\ \hat{c}_1 + (u_2/u_1)\hat{c}_2.$$

Substituting the observed values for C, c_1, and c_2, and rewriting, we have:

$$\hat{C}/c_1 = s_1 + (u_2/u_1)\ (c_2/c_1).$$

From each of the time periods of fishing during the cruise, we have a pair C/c_1 and c_2/c_1. The quantities s_1 and u_2/u_1 are estimated by the intercept and slope, respectively, of the linear regression of C/c_1 on c_2/c_1.

In the above model, the loss from a gillnet, $1\text{-}s_1$, applies to the fraction of fish disappearing from a gillnet unit during a 3-hour interval which is assumed to begin $1\frac{1}{2}$ hours after the fish enter the net. The loss from the time of entry to the beginning of the 3-hour interval is not included in the estimate of s_1.

The gillnet sets that yielded usable data on dropout are tabulated in Table 5 by time period and unit for both vessels. The weighted regression line, signifiat the five percent level, is given in Figure 20. The estimated loss of salmon from gillnets was 27 percent (80 percent confidence interval of 5–48 percent). The loss was attributable to dropouts and predation.

We were unable to estimate a dropout rate from the data obtained in the second experimental design in which gillnets were set in darkness and fished until noon. We found that salmon entered gillnets throughout the daylight fishing and, therefore, a direct measure of loss of salmon was not possible.

These preliminary fishing tests have shown significant losses of salmon from gillnets from fish dropping or struggling out of the nets, and from predation on entangled fish. We hope in the future to determine dropout rates for gillnets by means of direct observations.

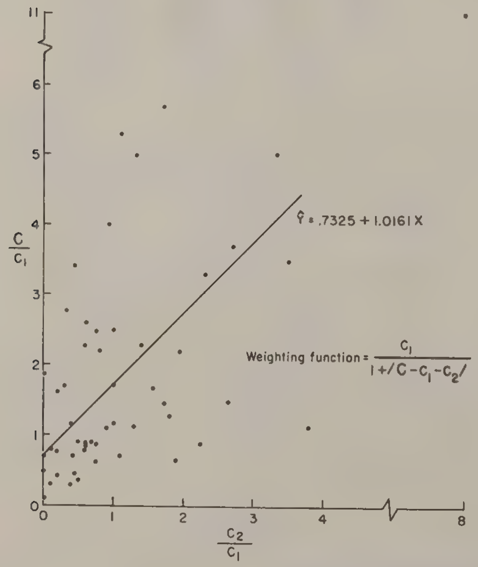

FIGURE 20. Regression of C/c_1 on c_2/c_1. C equals the catch in the 6-hour unit, c_1 the catch in the first 3-hour unit, and c_2 the catch in the second 3-hour unit.

Distribution and Abundance

Although the dropout study was not planned specifically to provide information on distribution and relative abundance of salmon, data were obtained which corroborated earlier findings and provided new knowledge of the distribution of sockeye salmon at the approaches to Bristol Bay. To fulfill the objectives of the cruise, it was important that both vessels make large catches of salmon which would provide data for reliable estimates of the dropout rate. The results of earlier cruises had established that concentrations of mature Bristol Bay sockeye salmon could be found south of the eastern end of the Aleutian Island chain in early June. Both the *Paragon* and the *Kelez* concentrated their fishing for the first half of the cruise in the area south of Unalaska and Umnak Islands. Fishing during the second half of the cruise was in the Bering Sea north of Unimak Island and the Alaska Peninsula at an average distance from shore of about 35 miles and where the depth of water averaged about 40 fathoms.

The most striking feature of the sets in the spring cruise was that a relatively high proportion of them (65 percent) caught more than 10 fish per shackle (50 fathoms) of gillnet (Fig. 21). In previous years, a catch of more than 10 fish per shackle in high seas fishing has been considered exceptionally high. The fact that over 65 percent of this season's catches were greater than 10 fish per shackle (ranging as high as 85 fish per shackle) indicated the tremendous numbers of Bristol Bay sockeye salmon present in the eastern Aleutian area during the spring of 1965.

In addition to the regular gillnet sets, the *Kelez* made five longline sets to obtain sockeye salmon for tagging (see section entitled "Ocean Mortality and Growth"). Four sets were made south of Unalaska Island and

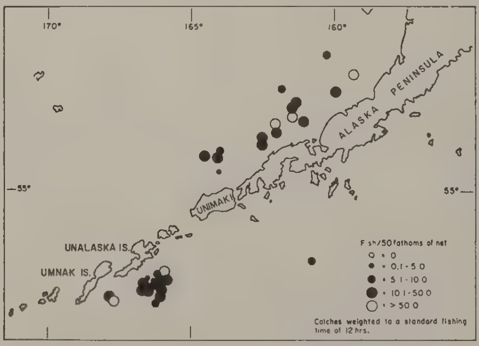

FIGURE 21. Relative abundance of sockeye salmon, June and July 1965.

TABLE 5. Salmon catches by time periods, RV *George B. Kelez* and MV *Paragon*, spring cruise, 1965.

Date	Position		Set no.	Time period (see Fig. 17)	Catch		
	Lat. (N)	Long. (W)			1st 3-hr. Unit (c_1)	6-hr Unit (C)	2nd 3-hr. Unit (c_2)
RV *George B. Kelez*							
6/6	53—23	166—05	1	I	8	1	0
				III	2	7	7
6/7	53—01	166—03	2	I	49	92	0
				III	18	50	6
6/8	53—06	166—00	3	I	13	69	14
				II	14	16	18
				III	18	21	7
6/14	53—07	166—37	8	I	38	44	38
				II	38	87	22
				III	22	38	6
6/15	52—55	167—43	9	I	100	107	91
6/22	55—50	164—00	13	I	73	65	36
				II	36	13	18
				III	18	9	0
6/23	56—10	162—31	14	I	22	49	17
				II	17	28	3
				III	3	17	5
6/25	57—01	159—58	15	I	25	57	35
				II	35	23	67
				III	67	112	105
7/2	56—24	162—00	21	II	44	40	30
				III	30	38	54
MV *Paragon*							
6/1	53—43	160—44	1	I	3	10	7
				II	7	12	7
				III	7	24	3
6/7	53—20	165—52	3	I	167	129	19
				II	19	13	0
6/8	53—26	165—57	4	I	170	147	105
6/12	52—52	166—12	7	I	5	13	3
				II	3	15	4
				III	4	10	3
6—14	53—15	166—38	8	III	67	21	7
6—15	52—57	167—41	9	I	53	33	40
				II	40	160	37
				III	37	27	40
6/18	53—16	166—15	11	I	9	4	2
6/21	55—48	160—31	12	I	61	18	23
				II	23	20	14
				III	14	11	8
6/22	55—55	164—00	13	I	3	15	10
6/23	56—06	162—30	14	I	44	50	166
				II	166	130	31
				III	31	14	14
6/25	56—37	161—30	15	I	89	132	235
6/28	57—06	161—56	17	II	7	5	3
				III	3	11	8
6/29	56—47	161—25	18	I	15	22	26
7/1	56—30	161—05	19	I	1	11	8
				II	8	7	6
				III	6	15	6
7/2	56—17	162—00	20	II	8	7	18
				III	18	40	35
			Total	52	1,778	2,109	1,467

one in Bristol Bay. The catches ranged from 7 to 132 fish (7 to 200 fish when weighted to 1,000 hooks). The catch of 200 fish per 1,000 hooks at the Bristol Bay station was relatively high and further demonstrated the great abundance of sockeye salmon.

Variation was considerable in the size of the gillnet catches at the 18 stations south of Unalaska and Umnak Islands even though most stations were in a relatively small area (Fig. 21). These stations were about 10 to 40 miles offshore (average 22 miles) and where depths were 100 to 1,000 fathoms. The two largest catches (over 50 fish per shackle) were made about 20 miles offshore in water of 200 to 500 fathoms. Catches greater than 10 fish per shackle were made about 10 to 35 miles offshore.

The fishing stations in the Bering Sea and along the north side of the Alaska Peninsula were generally farther offshore than those in the North Pacific. With the exception of two stations 65 miles offshore, all were between 20 and 50 miles (average 32 miles) offshore and where water depths were 30 to 50 fathoms. Of the 14 stations less than 50 miles offshore, only two had catches of less than 10 fish per shackle. Three stations at which catches were over 50 sockeye salmon per shackle were between 30 and 35 miles from shore and in waters 30 to 40 fathoms deep. At two stations well offshore (65 miles), catches were less than 10 fish per shackle. Although fishing north of the Alaska Peninsula was restricted to within 70 miles of the coast, catches suggested that the main route of sockeye salmon to Bristol Bay rivers was along a fairly narrow band approximately 40 miles north of the Alaska Peninsula.

Fall Cruise

In October and November the RV *George B. Kelez* fished a series of stations south of Attu Island along long. 173°E between lats. 40°N and 52°N and along an east-west line at lat. 50°N between longs. 167° and 178°E. The locations of these fishing stations are illustrated in Figure 22.

The standard gillnet string consisted of 28 braided nylon nets: 12 of $4\frac{1}{2}''$, eight of $3\frac{1}{2}''$, and four each of $5\frac{1}{4}''$ and $2\frac{1}{2}''$ mesh. At four southern stations (No.'s 8, 9, 10, 11) we added three nets of 2″ mesh to the string.

Catch data for salmonids, by set number and location, are listed in Table 6. Miscellaneous catches of non-salmonid fishes are discussed in a later section.

Distribution and Relative Abundance

Catches of sockeye salmon were composed primarily of fish that had spent one or two winters at sea. One-winter-at-sea fish (mainly age 4_3) occurred from lats. 48°N to 52°N along long. 173°E and from longs. 178°E to 167°E along lat. 50°N. Their major abundance, however, was between longs. 172°E and 175°E at lat. 50°N (Fig. 23). Two-winter sockeye salmon (primarily age 5_3) were distributed similarly to 1-winter fish; they were most abundant between lats. 49°N and 50°N between longs. 172°E and 173°E. The two 3-winter sockeye salmon were captured at lat. 50°N, long. 170°E.

The catch of chum salmon included four age groups: 2-, 3-, 4-, and 5-year-olds. Two-year-old chum salmon were most abundant in the western part of the sampling area, whereas the older chum salmon (mostly 3- and 4-year-olds) had a wider distribution (Fig. 23).

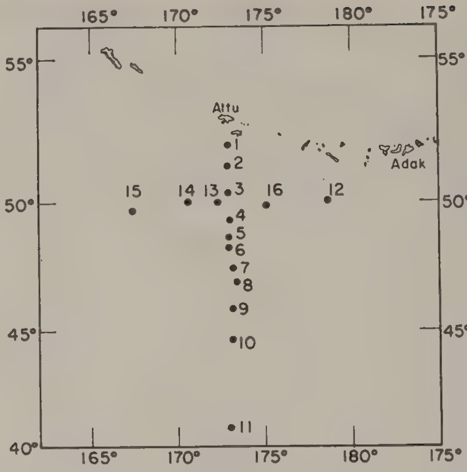

FIGURE 22. Location of fishing stations of the RV *George B. Kelez*, October 2-November 5, 1965.

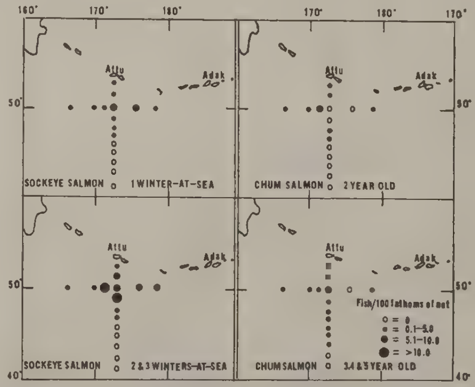

FIGURE 23. Relative abundance of sockeye and chum salmon, October-November 1965.

Table 6. Catches of salmon and steelhead, RV *George B. Kelez*, fall cruise, 1965.

Set no.	Date	Position		Surface temp. (°C)	Number of shackles	Species[1]					
		Lat. (N)	Long. (E)			Sockeye	Chum	Chinook	Coho	Steelhead	Total
1	10/3	52—00	172—58	8.6	28	14	1	—	—	—	15
2	10/4	51—16	172—58	9.1	28	78	45	5	—	3	131
3	10/5	50—19	173—00	9.3	28	98	50	—	—	—	148
4	10/6	49—15	172—58	9.9	28	140	36	—	—	—	176
5	10/7	48—22	173—00	9.9	28	14	28	—	—	—	42
6	10/8	48—40	172—59	9.9	28	16	21	1	—	—	38
7	10/9	47—30	173—05	10.2	28	—	27	—	—	—	27
8	10/10	47—00	173—20	11.6	31	—	2	—	—	—	2
9	10/12	45—51	173—02	10.8	31	—	2	—	—	—	2
10	10/13	44—40	173—02	12.0	31	—	—	—	—	—	—
11	10/15	41—00	173—00	16.3	31	................net lost................					
12	10/24	50—02	178—32	8.3	28	91	7	—	—	2	100
13[1]	10/28	50—00	172—17	7.1	28	90	53	—	—	8	151
14	10/29	50—01	170—38	6.3	28	33	25	—	10	1	69
15	11/1	49—44	167—28	7.0	28	8	9	—	11	—	28
16	11/5	49—57	175—03	5.8	28	94	1	—	1	4	100
				Total		676	307	6	22	18	1,029

[1] One pink salmon caught in set no. 13.

A change in dominance from sockeye salmon to chum salmon took place in the area between lats. 47°N and 49°N along long. 173°E. At about 49°N, sockeye salmon constituted 80 percent of the catch; near lat. 48°N sockeye salmon made up 38 percent of the catch, whereas at 47°N the catch was entirely chum salmon. Only chum salmon entered the catch between lats. 45°51′N and 48°22′N; no salmonids were caught south of 45°51′N.

The few coho salmon and steelhead were taken primarily on the east-west cruise, at lat. 50°N between long. 178°E and 167°E. Set No. 2 at lat. 51°16′N, long. 173°E netted five of the six chinook salmon. One pink salmon was caught at 50°N, 173°E.

Length and Age Composition

The area of overlap in length frequencies between 1- and 2-winter sockeye salmon was small; the separation point was at about 435 mm (Fig. 24). Only two 3-winter sockeye salmon were captured.

Overlap of length frequencies of 3- and 4-year-old chum salmon was extensive, although 4-year-olds averaged almost 38 mm longer than 3-year-olds. Length frequencies of 2- and 3-year-old chum salmon had little overlap; the separation point was at approximately 425 mm (Fig. 25).

Table 7 gives the percentage age composition by set number for sockeye and chum salmon. The majority of sockeye salmon (66.5 percent) were 2-winter-at-sea fish; age group 5_3 constituted 47.7 percent of the total catch.

Of the four age groups (2-, 3-, 4-, and 5-year-olds) of chum salmon represented in the catches, 3- and 4-year-olds made up 74.2 percent and 2-year-olds 25.1 percent of the total catch.

Salmon other than sockeye and chum constituted a small part of the total catch. Coho salmon ranged in length from 296 to 347 mm; all were in their first

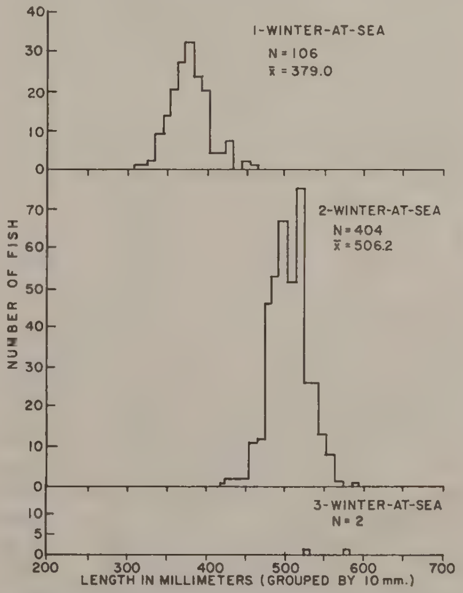

Figure 24. Length frequencies of sockeye salmon by number of winters at sea, fall cruise, RV *George B. Kelez*, 1965.

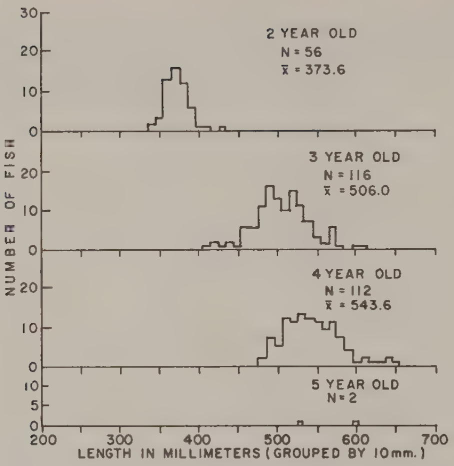

Figure 25. Length frequencies of chum salmon by total age, fall cruise, RV *George B. Kelez*, 1965.

summer at sea. Coho salmon scales showed that 10 had migrated to sea in their second year of life and seven in their third year of life. Scale readings from six chinook salmon indicated that five were age 4_2, and one was age 5_2. Lengths ranged from 606 to 710 mm. Examination of scales from 18 steelhead trout showed that 13 were in their second year of ocean life, three in their third year and two in their fourth year. Lengths varied from 528 mm to 907 mm. The one pink salmon taken at lat. 50°N, long. 172°E was 493 mm long and in its second year of life.

Maturity

Criteria for determining maturity of salmon in the fall have not yet been established ; with our present knowledge it is difficult to determine if a fish will mature the following year. Some of the chum salmon captured (three males and eight females), however, were obviously mature and would have spawned in late 1965 or early 1966. Chum salmon spawn as late as January in many of the rivers of Japan (Sano, MS 1964) and North America (Neave, 1966).

Miscellaneous Catches

Non-salmonid catches included 20 salmon sharks (*Lamna ditropis*), four blue sharks (*Prionace glauca*), one daggertooth (*Anotopterus pharao*), 30 pomfret (*Brama rayi*), 12 Atka mackerel (*Pleurogrammus monopterygus*), one bluefin tuna (*Thunnus saliens*), and one albacore (*Thunnus alalunga*). Salmon sharks were captured at most stations throughout the sampling area. Blue sharks occurred only at lat. 44°40′N, long. 173°E ; three were tagged with Petersen disc tags and released in cooperation with the shark tagging program of the

Table 7. Percentage age composition of sockeye and chum salmon by set number, fall cruise, RV *George B. Kelez*, October-November 1965.[1]

Sockeye Salmon

	Set no. and sample size											
	1	2	3	4	5	6	12	13	14	15	16	Total *N*
Age	12	60	86	119	12	16	72	78	29	5	74	563
3_2	37	4	12	—	—	7	16	—	3	—	12	7.0
4_3	27	29	42	17	10	28	17	8	26	67	28	24.0
5_4	—	2	1	1	—	—	5	2	—	—	5	2.1
3_1	—	—	—	2	8	6	—	—	—	—	—	1.0
4_2	27	8	7	18	32	—	15	23	13	—	8	13.7
5_3	9	55	36	55	50	53	46	58	45	33	45	47.7
6_4	—	2	2	7	—	6	1	7	13	—	2	4.1
5_2	—	—	—	—	—	—	—	1	—	—	—	0.2
6_3	—	—	—	—	—	—	—	1	—	—	—	0.2

Chum Salmon

	Set no. and sample size													
	1	2	3	4	5	6	7	8	9	12	13	14	15	Total *N*
Age	1	41	48	35	27	21	27	2	1	6	51	24	4	288
2	100	9	—	—	21	11	—	—	—	87	66	56	31	25.1
3	—	46	25	66	24	66	75	—	—	—	9	27	23	38.3
4	—	45	75	34	25	23	22	100	100	13	25	14	46	35.9
5	—	—	—	—	—	—	3	—	—	—	—	3	—	0.7

[1] Data adjusted to equal fishing effort for the various age groups.

American Institute of Biological Sciences. Pomfret were taken in four sets; at lat. 47°30′N, long. 173°E, and stations south. Both tunas occurred at lat. 44°-40′N, long. 173°E in Set No. 10, where surface water temperature was 12°C. This was the first catch of bluefin tuna by our research vessels in 11 years of gillnetting.

VISCERAL ADHESIONS IN HIGH SEAS SALMON

Earlier reports (French, 1965) noted the incidence of sockeye salmon afflicted with multiple visceral adhesions. Sockeye salmon taken during the winter and spring cruises of 1965 were examined to determine the incidence of adhesions.

Sockeye salmon with adhesions were taken in nearly every catch of this species during the winter cruise. The adhesions occurred in approximately 22 percent of the sockeye taken; they were found most often in males (66 percent) and in fish in their second winter at sea (78 percent).

Examination of 5,109 mature sockeye salmon caught in June and July 1965 during their migration to Bristol Bay showed an incidence of visceral adhesions of only 0.7 percent. This percentage was much less than that during the fall cruise of 1964 (19 percent) and the winter cruise of 1964 (26 percent). This reduction in the incidence of adhesions in the Bristol Bay sockeye sampled in the spring of 1965 indicated that the condition is either fatal or temporary if substantial numbers of the sockeye salmon sampled in the fall and winter were maturing Bristol Bay fish. Recent studies of sockeye salmon taken in the Gulf of Alaska have led Margolis[1] to believe that the adhesive condition is a transient one.

During the fall cruise, sockeye salmon with visceral adhesions were taken in every catch of this species. Adhesions occurred in approximately 15 percent of the sockeye taken. This percentage is similar to that observed during the 1964 fall cruise (19 percent). In contrast to the winter cruise, there was little difference in incidence of adhesions by sex (males 16 percent; females 14 percent). The incidence was highest (22 percent) in 1-winter-at-sea sockeye.

SUMMARY

1. Research cruises in 1965 were made to study salmon distribution in the northwest Pacific Ocean during the winter and fall and to determine dropout rates of salmon caught in gillnets in the eastern North Pacific and eastern Bering Sea during the spring.

2. In the winter, 2-, 3-, and 4-winter-at-sea sockeye salmon were taken throughout the area between longs. 178°W and 167°E, and from the Aleutian Island chain to lat. 45°N. One-winter-at-sea sockeye were abundant in the area bounded by lats. 46° and 47°N, and longs. 180° and 175°E. Chum salmon, ages 4, 5, and 6 years, were found principally between longs. 178°W and 175°E. No 2- or 3-year-old chum salmon were taken. Pink and coho salmon and steelhead were taken south of lat. 45°N and between long. 180° and 177°E.

3. The older sockeye salmon taken in winter were 53 percent 2-winter, 45 percent 3-winter, and two percent 4-winter-at-sea fish. Age 5_3 dominated the 2-winter fish, ages 5_2 and 6_3 were about equally represented among the 3-winter fish, and age 4_3 dominated the 1-winter sockeye.

4. Results of applying gonad weight criteria on males, and serological methods on females, for judging maturity of winter salmon indicated most of the 2- and 3-winter sockeye salmon were maturing. Nearly all of the chum salmon sampled were maturing.

5. Experimental gillnet fishing at depths of 24 to 72 feet revealed that relatively few salmon were at these depths compared with the abundance in the upper 24-foot layer.

6. Winter salmon catches indicated a relation between salmon distribution and surface temperatures: sockeye salmon were taken at stations where surface temperatures were below 5°C; chum salmon at stations with surface temperatures generally above 3°C; and pink and coho salmon and steelhead only at stations with surface temperatures of about 7°C.

7. A comparison of catches by 3-hour periods in the northeastern Pacific in June showed that the largest catches were made between the hours 8–11 p.m. and smallest between 5–8 a.m.; in the eastern Bering Sea the largest catches were made from 11 p.m. to 2 a.m. and the smallest from 2–5 a.m.

8. Studies of gillnet dropouts indicated a loss of salmon of 27 percent. This loss was attributed to dropouts and predation.

9. Relatively large catches of sockeye salmon were made in the northeastern Pacific and in the approaches to Bristol Bay during June. These catches were indicative of the very large run to Bristol Bay in 1965.

10. In October along 173°E long., between lats. 48°N and 51°N, immature sockeye salmon which had spent two winters at sea dominated the catches. Sockeye which had spent only one winter at sea were most abundant at lat. 50°N. Chum salmon had their greatest abundance at lat. 50°N near long. 172°E. A change in dominance from sockeye to chum salmon occurred in the area immediately to the south of lat. 49°N. Only chum salmon appeared in the catches south of lat. 48°22′N, and no salmonids were caught

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[1] Leo Margolis, Fisheries Research Board of Canada, Biological Station, Nanaimo, B. C. (personal communication).

south of lat. 45°51′N.

11. Sockeye salmon (mainly 2-winter fish) were most abundant on the east-west leg of the fall cruise along lat. 50°N between longs. 178°E and 172°E, whereas 2-year-old immature chum salmon predominated between longs. 170°E and 172°E. All of the steelhead and coho salmon were captured at stations north of lat. 49°30′N ; most of the coho salmon were at the two stations farthest to the west.

12. Of the sockeye salmon caught, 66.5 percent were 2-winter-at-sea fish ; 1-winter sockeye constituting most of the remainder. Three- and 4-year-old chum salmon were almost equally abundant and accounted for 74.2 percent of the total ; 2-year-olds made up most of the remainder.

13. Visceral adhesions occurred in about 22 percent of the sockeye salmon taken during the winter cruise ; adhesions were found in only 0.7 percent of the maturing sockeye taken south of Unalaska Island and at the approaches to Bristol Bay during June, but 15 percent of the sockeye captured during the fall cruise had visceral adhesions.

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OCEANOGRAPHY

by F. Favorite

The present objective of oceanographic research conducted for the INPFC is to permit prediction of the abundance and location of species and stocks of Pacific salmon, through knowledge and understanding of physical, chemical, and biological conditions in the salmon environment. This implies that salmon respond in a predictable manner to changes in their environment. Evidence of this behavior has been presented in previous INPFC Annual Reports.

Our early investigations were carried out during spring and summer as an adjunct to experimental salmon fishing ; voluminous amounts of oceanographic data were collected. Using these data, we were able to show that southern limits of salmon distribution during winter and during summer in the central, northern North Pacific Ocean were delineated by oceanographic features. Also, we have indicated that the annual anomalous westward movement south of the Aleutian Islands of mature sockeye salmon returning to Bristol Bay appears to be related to the intense westward flow of water in the Alaskan Stream. Further, it has been suggested that the westward extent of these sockeye salmon appears to be at the western terminus of the Alaskan Stream which diverges near long. 170°E, sending one branch northward into the Bering Sea, and the other southward where it merges with the eastward flowing Subarctic Current near lat. 49°N.

Distribution of Sockeye Salmon in Relation to Environment

During the past winter, through the accumulation of field data, we were able to strengthen an hypothesis that the temperature front near lat. 45°N in the central part of the ocean (Favorite and Hanavan, 1963) may denote the southern extent of the range of sockeye salmon throughout the year. The results of Canadian research in the Gulf of Alaska during the period April 9 to May 6, 1962 (INPFC Annual Report 1962, pp. 31–32) clearly showed a marked separation of sockeye and pink salmon ; the former were concentrated in the central part of the Gulf, and the latter off the Washington coast. It is generally believed that such a separation is chiefly due to surface temperatures, and that the pink salmon are associated with the warmer water in the southern part of the Gulf. Since the surface temperatures during spring indicate only a uniform gradient throughout the area, and the values are increasing approximately 1°C approximately every two weeks, this correlation appears to be vague. Rather, the distribution of sockeye salmon appears to be distinctly related to the distribution of a temperature-minimum stratum indicative of a particular type of vertical circulation. This relation was shown by using temperature data along long. 155°W from the 1962 winter cruise of the RV *Bertha Ann* (Favorite *et al.*, 1964) to show the vertical structure of the temperature-minimum stratum (less than 4.0°C) at 150 meters depth, and temperature data from the 1962 spring cruises of the C.N.A.V. *Oshawa* and *Whitethroat* (Fish. Res. Bd. Can., 1962) to show the horizontal distribution of the temperature-minimum at 150 meters depth in the Gulf of Alaska. The correlation between the distribution of this temperature structure and the concurrent distribution of sockeye salmon at this apparently critical time of the year (immediately prior to homing migrations) is remarkable (Fig. 26).

As indicated in numerous previous INPFC Annual Reports, this temperature-minimum stratum is caused primarily by the advection of cold water from the western Pacific and winter turnover, and its southern boundary is denoted by a temperature front indicated by the vertical slope of the 4° or 5°C isotherm. During salmon fishing by the RV *George B. Kelez* south of the Aleutian Islands along long. 179°E and long. 167°E, in February and March 1965, the boundary was encountered near lat. 45°N along long. 179°E. No sockeye salmon were caught in surface gillnets south of the boundary (which during this particular period was also denoted by a sharp gradient of surface salinity—see Fig. 27). Fishing was not conducted far enough southward at long. 167°E to reach the boundary; sockeye salmon were caught at all fishing stations. These vertical sections of temperature also clearly show the relative homogeneity of temperature in the water column during winter. Summer heating at the surface increases surface temperatures from 2°C to higher than 10°C and a thermocline with a magnitude of approximately 7°C forms in the upper 100 meters; thus, the boundary is not detected by surface temperature during summer and fall. However, other basic properties of the water masses northward and southward of the boundary which have influenced the distribution of the sockeye salmon during winter are still present; and, of course, below 100 meters, the winter temperature regime persists throughout the year.

Therefore, it appears that the southern limit of sockeye salmon in the central part of the ocean may be determined by a change in water mass at a position delineated by the temperature distribution. Attempts

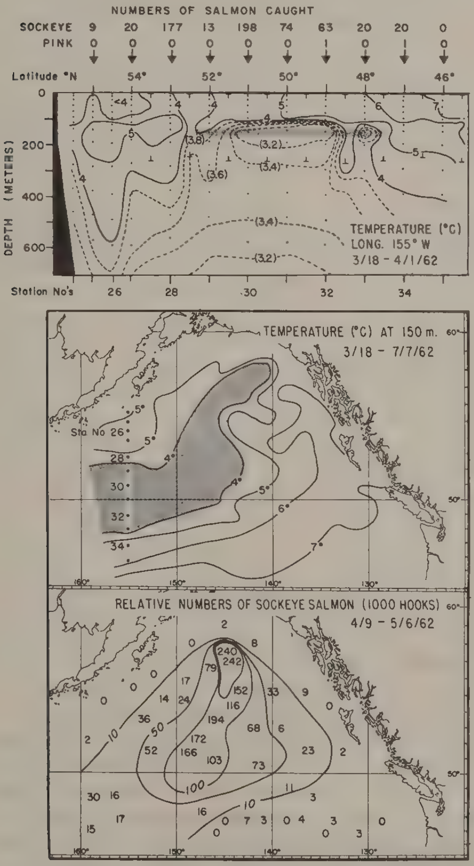

FIGURE 26. Vertical temperature distribution south of Kodiak Island during late winter and early spring 1962 showing temperature-minimum stratum at 150 m depth, and the horizontal extent of the stratum in the Gulf of Alaska, compared with the distribution of sockeye salmon.

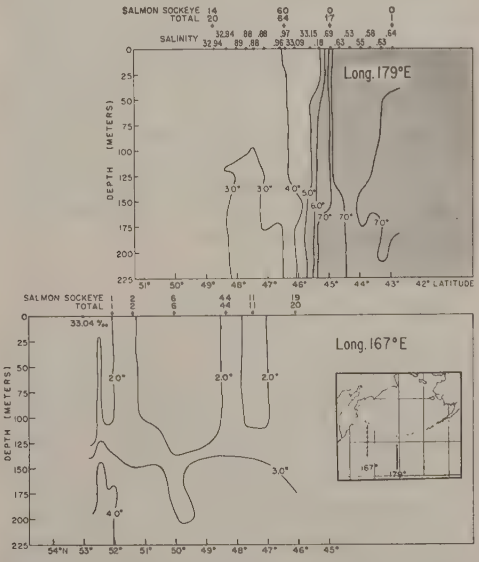

FIGURE 27. Vertical temperature distribution along long. 179°E and 167°E. Shaded area at long. 179°E, south of temperature front near lat. 45°N, indicates absence of sockeye salmon.

will be made next winter to locate the temperature front prior to determining fishing locations, and fishing will be conducted at closely spaced intervals north and south of it to determine the distribution of salmon at the boundary between the two water masses.

Chemical Studies

In the area of marine geochemistry, the principal emphasis during the year was on the development of techniques for the study of trace elements in sea water. In a preliminary adaptation of atomic absorption methods to sea water analysis, we were able to employ a simple extraction procedure for the quantitative removal of manganese, iron, and zinc from sea water into an organic solvent, suitable as a medium for atomic absorption spectrometry. A report on these procedures has been published (Joyner and Finley, 1966). This work has clearly demonstrated the feasibility of the routine measurement of the trace-element content of sea water by modern spectrometric methods. Much additional work remains to be done, particularly in the development of techniques for the processing of large volumes of sea water for high-precision analyses at the parts-per-billion level and lower. This type of research is of a somewhat basic character; immediate applications most readily apparent are for supplementing physical information in the determination of the properties and movements of water masses. Applications to biological problems related to salmon fisheries will require more extensive research into the ecology of plankton than can be undertaken with our present capabilities. Therefore, until routine methods can be devised to measure trace elements, these studies will be supported by funds from other sources. We feel, however, that the studies are basic to our knowledge of processes in the ocean related to salmon distribution; when the techniques are forthcoming they will be used in our INPFC research.

Geostrophic Transport Studies

Many studies of the circulation in the North Pacific Ocean have used currents derived from geostrophic calculations (which assume a balance between horizontal Coriolis forces and horizontal pressure forces), but there are few instances of use of geostrophic transports. For many purposes the transport is as significant as the surface current, and cannot necessarily be derived from charts of surface geostrophic flow. A knowledge of currents and transports is indispensable to an understanding of the processes acting in the ocean. Accurate and reliable direct observations are slowly becoming available, but are still so few as to be almost nonexistent. The cost and difficulties associated with obtaining data from current meters and neutrally buoyant floats would indicate that, for some years, we will still depend upon indirect means for most of our knowledge of the surface and deep circulation.

In indirect analysis, the circulation is inferred either from the distribution of properties or from geostrophic currents calculated from hydrographic data. Since the number of stations over the North Pacific Ocean for any one season has been small, most of the circulation schemes proposed for the region have been derived from a study of water properties. Although there are geostrophic calculations for limited areas of the ocean and particular cruises, calculations of deep currents are lacking, and there appear to be no transport charts computed from station data for the North Pacific Ocean. One reason for the lack of such calculations is that the integrated geostrophic transport is sensitive to choice of a proper reference level; that is, a depth at which the water is at rest. Since relatively few stations extend below 1,000 meters, this depth has been used as a reference depth for dynamic calculations simply because it is the deepest depth for which extensive observations are available. This choice of depth provides an acceptable surface topography, but little confidence can be placed in these geostrophic transports.

As part of our INPFC program, we have investigated two possibilities for obtaining transport values. The first method has been to prepare synthetic hydrographic data for depths below 1,200 meters. We have assumed that at this depth the circulation is slow, and is likely to be driven in response to factors that will produce a flow pattern which will not vary much from year to year; that is, the short-term factors are damped out in the deep circulation. All known deep stations have been used to prepare average temperature and salinity charts for the North Pacific Ocean for standard depths from 1,000 to 5,000 meters. Although there is some evidence of possible changes in the deep water on a time scale of tens of years, the evidence from the stations which we examined—with the exception of the 1936 *Bushnell* stations, all taken between 1951 and 1963—indicates that changes over the 12-year period were slight. These values have been coupled with actual observed station values from 1958 to provide a network over the ocean extending to the bottom. Geostrophic transports have been calculated from these data to show the integrated geostrophic transport in the North Pacific Ocean (Fig. 28).

Our second method has been to use the theories of wind-driven ocean circulation to compute the circulation and transport from the observed or in-

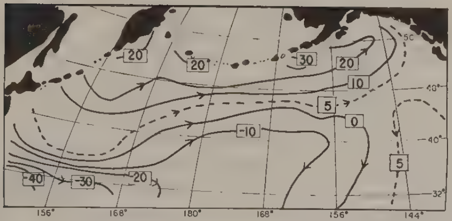

FIGURE 28. Geostrophic transport in the North Pacific Ocean ($10^6 m^3/sec$).

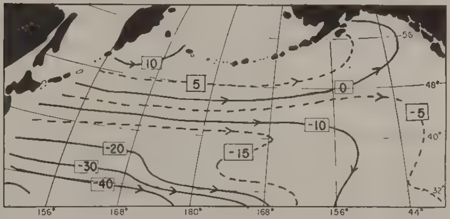

FIGURE 29. Wind-driven transport in the North Pacific Ocean ($10^6 m^3/sec$).

ferred wind or pressure field over the ocean surface. In this procedure, the surface barometric pressure field is directly related to the integrated geostrophic transport in the ocean. This method has been used to predict the general transport for 1958 (Fig. 29). The computation of transport from the wind or pressure field is of great interest because it appears to provide information as reliable as the best estimates from the geostrophic calculations, and the base data are quickly and easily available. It does not, however, provide the information on the internal distribution of transport which is provided by the geostrophic method.

Both of these methods provide useful and necessary information and will be checked closely against direct observations as they become available. We plan to develop both methods more fully. The transport from the wind or pressure field will provide us with a quick, reliable estimate of the surface circulation and the total transport. When this is combined with hydrographic data observed at the 1,000-meter stations, and the long-term values for deeper water, it will provide information about the internal distribution of currents in the ocean.

A definitive paper on the nature, extent, and cause of the Alaskan Stream has been submitted for publication in the INPFC Bulletin series (Favorite, MS 1965). It shows that relative transport in this narrow current system along the south side of the Aleutian Islands can be predicted from knowledge of the distribution of sea level pressure in the Gulf of Alaska and the vicinity of the Aleutian Islands and that the system can be traced as far west as long. 165°E south of the Aleutian-Komandorski Island chain.

TELEMETRY BUOY PROGRAM

Our research has indicated that within the Subarctic Region, where salmon spend the marine phase of their life cycle, a reasonably ordered circulation system exists but significant annual fluctuations occur that appear to affect the distribution of salmon. We realize that the difficulties are great in ascertaining circulation patterns accurately enough to permit selecting specific fishing locations at the boundaries of current systems, even on a seasonal basis, with ships available to the Commission; we believe that drifting, telemetry buoys will be the best method of obtaining the information required. No buoys are available equipped with the data-recording and telemetry equipment required, and it will be a year or two before a complete measuring and reporting system is functional, but a system capable of placing into position, and obtaining environmental data from a network of drifting buoys would provide a continuous synoptic picture of oceanographic conditions. When we are able to relate movements of salmon to these conditions, such a system might easily provide the basis for controlling the time and area that oceanic salmon fishing could be conducted in the Subarctic Region. Also, by denoting the locations of salmon stocks at any time of the year, the system would permit research vessels to sample the size of stocks from specific areas months or even a year before the salmon return to parent streams. We have been assured that by 1969 satellites capable of relaying data from such a system will be available, and we have only one or two years to decide if we will establish a buoy system and to make arrangements for the inclusion of our data in the satellite data-acquisition system. The operation of the system would require the cooperation of all three member nations of the Commission. A total of 56 buoys would be used in the initial experiment; every four months a series of seven buoys would be released off the Kuril Islands. Present knowledge indicates that the buoys will drift eastward and will require about two years to reach the North American continent, where most would be recovered. After recovery and repair, each series would be transported back to the Kuril Island area and released again. An approximate distribution of buoys at the end of a 2-year period indicates that good coverage of the Subarctic Region would be obtained (Fig. 30). Of course, daily positioning and transmission of oceanographic data by satellite would portray an infinitely more complex picture of individual buoy drift, as well as permit early recovery of buoys in danger of going aground.

One might argue that shoreward-migrating salmon move at speeds greater than those found in ocean current systems, and this may or may not be true. But these migrations involve only a few months of the several years that some species of salmon spend in the ocean.

An indication of the information that might be forthcoming from such a buoy-satellite system is reflected by preliminary results of a drift-bottle study conducted aboard a ship of opportunity, the S.S. *Java Mail*, last winter. Because previous studies had indicated that only two percent of the bottles would be recovered, 96 bottles were released at approximately 8-hour intervals at 40 locations during the 12-day period from October 20 to November 1, 1964, as the vessel proceeded from Seattle to Hong Kong (Fig. 31). A total of 59 recoveries were received by September 1, 1965. Some released as far west as long. 165°W were recovered along the west coast of Canada and the United States, and thus more or less duplicated the results of a study conducted during 1962 (Favorite, 1964). However, the northward flow along the coast shown by recoveries from the inshore stations is new information, and may affect the migration of salmon off the west coast of North America.

Some of the bottles released in the central part of the ocean (long. 175°W to 169°E) drifted northward and were reported recovered on various Aleutian Islands during early spring. This drift was not expected because the results of a previous winter cruise (February to April 1962) showed that the westward flow of the Alaskan Stream south of the Aleutian Islands, extensively documented during the summer, could also be expected during winter as far westward as long. 175°W, and we assumed that winter conditions were therefore similar to summer conditions (Favorite *et al.*, 1964). This drift-bottle study indicates there was a westward surface current along the south side of the Aleutian Islands; but there also was present a significant northward surface flow in the central Aleutian area last winter that, although perhaps wind-driven, could have had a significant effect on the movements of salmon in this area. If, at each location, instead of 96 drift bottles we had released a drifting telemetry buoy, whose position and surrounding environmental conditions were reported daily, we would have extensive information to correlate with any anomalies in the oceanic distribution of salmon this year.

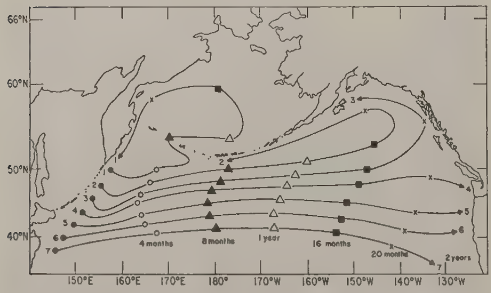

FIGURE 30. Estimated locations, at 4-month intervals, of drifting buoys released at indicated locations off the Kuril Islands.

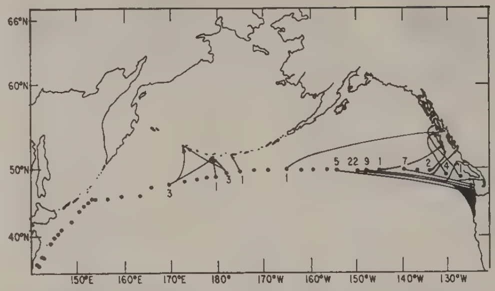

FIGURE 31. Drift bottle experiment, the SS *Java Mail*, October to November 1964. Dots show 40 locations where groups of 96 bottles were released. Numbers indicate total recoveries from individual groups as of September 1, 1965.

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OCEAN MORTALITY AND GROWTH

by R. H. Lander, K. N. Thorson,
R. C. Simon, T. A. Dark, and G. K. Tanonaka

For sockeye, chum, and pink salmon of commercial size, an accumulating body of evidence now indicates that increases in stock weight from growth of individuals continue to exceed the losses in stock weight from natural mortality until mature fish reach both the North American and Asian coasts (Ricker, 1962, 1964; Parker, 1963; Fredin, 1964; Hirschhorn, 1966). The general conclusion is that pelagic fishing reduces potential yields.

Beyond this general conclusion and its significance to sound resource management, however, remain problems for which definitive research techniques are not yet available. For instance, Parker (1962) noted that "A more direct approach designed to measure mortality directly is needed, and such experiments must be repeated often enough to describe annual variability."

Direct proof is seldom if ever available to support the assumptions required in estimating natural mortality (Beverton and Holt, 1957; Ricker, 1958). The only direct estimates of short-term marine mortality in Pacific salmon available are those based on offshore and inshore tagging of Asian chum and sockeye salmon about 30 years ago (Taguchi, 1961a, 1961b). For sockeye, the estimate of natural mortality was 50 percent during the last month of life at sea (Taguchi, 1961b). After pointing out that 44 percent of the coho salmon held in tanks died within six hours of capture by troll gear offshore, whereas all survived in the Taku River of Alaska after exercise comparable with fighting the troll gear (Parker *et al.*, 1959), Parker (1963) contended that the Japanese work cited above failed to demonstrate any natural mortality in Pacific salmon at all. Evidently as maturing salmon move toward the coast, physiological changes render them less vulnerable to mortality associated with the stress of capture and tagging. Among the additional assumptions that Taguchi (1961a, 1961b) had to make was that survivors of salmon tagged offshore and inshore were exploited at the same rate in the coastal fishery.

Parker (1964) reported another example of the difficulty in assessing short-term rates of natural mortality in Pacific salmon. Pink salmon smolts of the 1960 brood originating in Hooknose Creek were marked in two coastal areas of British Columbia. The mixing of those smolts with smolts from other populations, and removal of all populations at different and inexactly known rates by the commercial fishery in 1962, prevented the estimation of natural mortality during the first five weeks in salt water.

With this background, the Bureau of Commercial Fisheries conducted a tagging experiment on maturing Bristol Bay sockeye salmon during June and July 1965. Major objectives were: (1) to determine the feasibility of estimating terminal natural mortality by tagging during the last few weeks of ocean life; (2) to estimate growth over the same interval; and (3) to define physiological mechanisms of significance in the mortality of maturing salmon captured, tagged, and released at sea.

The present report contains basic information on tag releases and on recoveries reported through November 15, 1965, includes certain preliminary analyses pertinent to the problem of natural mortality, and describes research in progress under all three of the above objectives.

Release of Tags

Three vessels participated in the 1965 field studies. The Bureau of Commercial Fisheries research vessel *George B. Kelez* served as a base for tagging, and for physiological research and gillnet dropout studies discussed elsewhere in this report. The *Kelez* fished both longlines and gillnets. A purse seine vessel, the MV *Yaquina*, was chartered to capture fish for tagging, and most tag releases were made from this vessel. The Fisheries Research Institute of the University of Washington supplemented this research on June 7 by tagging from the MV *Commander*.

Figure 32 shows the general area and dates of tagging. All releases from June 6 through June 20 were west of 165°W long., and mainly south of Unalaska Island (see just below "Unalaska I." in Fig.

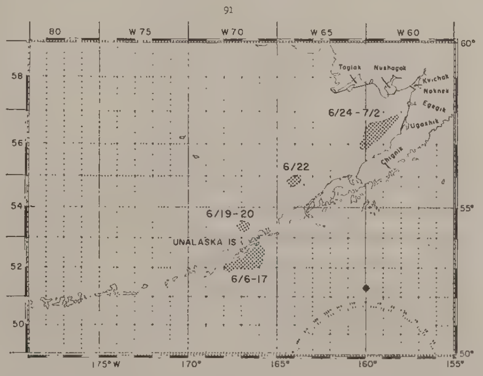

FIGURE 32. General area and dates of tag releases for the 1965 mortality and growth experiment on maturing Bristol Bay sockeye salmon.

TABLE 8. Data on tag releases and recoveries of sockeye salmon reported though August 23, 1965. Source: 1965 mortality and growth study on Bristol Bay sockeye salmon, by the Bureau of Commercial Fisheries.

	Releases					Number of recoveries by area[2]						
Vessel and date	Set no.	Lat. (N)	Long. (W)	Gear[1]	No. of fish	Togiak	Nushagak	Naknek Kvichak	Egegik	Ugashik	Bristol Bay unknown	Total
RV *George B. Kelez*												
6/6	K 2	53—28	166—04	G	91	—	—	—	—	—	—	—
6/7	K 3	53—06	166—09	G	72	—	—	—	—	—	—	—
6/10	K 5	53—30	166—19	L	33	—	—	1	—	—	—	1
6/11	K 6	53—30	166—18	L	110	—	—	4	1	—	—	5
6/12	K 7	53—30	166—19	L	7	—	—	1	—	1	—	2
6/13	K 8	53—07	166—37	G	91	—	—	—	—	—	—	—
6/14	K 9	52—55	167—43	G	65	—	—	—	—	—	—	—
6/17	K 10	53—13	166—20	G	59	—	—	—	—	—	—	—
6/22	K 13	55—50	164—00	G	49	—	—	—	—	—	—	—
6/26	K 16	57—23	159—24	L	71	—	—	16	2	1	1	20
				G	40[3]	—	—	—	—	—	—	—
6/28	K 17	57—21	159—22	L	9[4]	—	—	3	—	—	—	3
				G	31	—	—	—	—	—	—	—
6/30	K 19	57—30	159—55	G	113	—	—	12	3	—	1	16
				Total	841	—	—	37	6	2	2	47
MV *Yaquina*												
6/5	Y 2	53—51	166—16	P	1	—	—	—	—	—	—	—
6/6	Y 3	53—42	165—56	P	37	—	—	—	1	—	—	1
	Y 4	53—40	165—57	P	69	—	—	3	2	—	—	5
6/7	Y 5	53—33	166—02	P	164	—	—	5	3	—	—	8
	Y 6	53—32	166—06	P	330	—	—	17	—	—	1	18
6/8	Y 7	53—36	166—12	P	260	—	—	27	2	1	—	30
	Y 8	53—32	166—14	P	240	—	1	10	2	—	1	14
6/9	Y 9	53—30	166—19	P	136	—	—	14	2	—	—	16
	Y 10	53—28	166—19	P	187	—	—	10	1	—	—	11
6/10	Y 11	53—34	166—17	P	318	—	—	12	1	—	—	13
	Y 12	53—29	166—22	P	130	1	1	10	3	—	—	15
6/11	Y 13	53—34	166—15	P	74	—	—	3	—	—	1	4
	Y 14	53—31	166—25	P	359	—	—	8	2	—	—	10
	Y 15	53—29	166—25	P	84	—	—	10(1)	1	—	—	11(1)
6/12	Y 16	53—23	166—30	P	233	—	—	17	5	—	1	23
6/13	Y 17	53—19	166—41	P	308	—	—	27	2	1	—	30
6/14	Y 18	53—14	166—56	P	400	—	—	30	—	2	2	34
	Y 19	53—15	166—59	P	96	—	—	5	—	—	—	5
6/15	Y 20	53—13	166—54	P	308	—	—	15	3	—	2	20
6/16	Y 21	53—12	166—54	P	425	—	—	21	2	—	—	23
6/17	Y 22	53—11	166—56	P	31	—	(1)	1(1)	—	—	—	1(2)
6/19	Y 23	54—22	166—52	P	4	—	—	1	—	—	—	1
6/20	Y 24	54—22	166—52	P	36	—	—	3	—	2	—	5
6/24	Y 25	57—00	160—00	P	459	—	3	112(3)	25	3	2	145(3)
	Y 26	57—00	160—00	P	207	—	1	60	5	3	1	70
6/26	Y 27	57—25	159—12	P	225	1	1	57(1)	13	2	1	75(1)
6/27	Y 28	57—48	158—30	P	8	—	1	1	—	—	—	2
	Y 29	57—48	158—30	P	158	1(1)	16(2)	17	1	—	—	35(3)
	Y 30	57—49	158—25	P	49	1	3(1)	2	1	—	—	7(1)
6/30	Y 31	57—32	159—15	P	311	—	—	48(1)	8	4	4	64(1)

Continued . . .

Table 8. (Continued)

Releases						Number of recoveries by area[2]						
Vessel and date	Set no.	Lat. (N)	Long. (W)	Gear[1]	No. of fish	Togiak	Nush-agak	Naknek Kvichak	Egegik	Ugashik	Bristol Bay unknown	Total
	Y 32	57—28	159—11	P	230	—	1	47	6	2	1	57
7/1	Y 33	57—27	159—03	P	291	—	3	48	17	5	—	73
	Y 34	57—30	159—00	P	241	2	3	60	10	4	1	80
7/2	Y 35	57—32	159—00	P	328	—	2	81 (2)	17	2	1	103 (2)
	Y 36	57—34	159—04	P	208	—	4	59	9	1	3	76
				Total	6,945	6 (1)	40 (4)	841 (9)	144	32	22	1,085 (14)
MV *Commander*												
6/7	C 49	53—12	166—47	L	90	1	1	6	2	—	—	10
	C 50	53—23	166—32	P	150	—	1	15	3	—	—	19
				Total	240	1	2	21	5	—	—	29

[1] G=gillnet; L=longline; P=purse seine.

[2] All stream recoveries in parentheses.

[3] Fish held over from gillnet set K-15 on 6/25.

[4] Fish held over from longline set K-16.

Table 9. Summary of 1965 tag releases of sockeye salmon by release group, gear, tag type, and tagging treatment.

Group and gear	Tag type			Treatment			
	Disc	Spaghetti	Disc and spaghetti	Standard[1]	Immediate[2]	Oxygen[3]	Total
Offshore							
Purse seine	4,305*	42	33	4,380*	—	—	4,380
Longline	240	—	—	198	42	—	240
Gillnet	378	—	—	202	—	176	378
Sub-total	4,923	42	33	4,780	42	176	4,998
Inshore							
Purse seine	2,491	200	24	2,715	—	—	2,715
Longline	80	—	—	41	—	39	80
Gillnet	233	—	—	118	—	115	233
Sub-total	2,804	200	24	2,874	—	154	3,028
Total	7,727	242	57	7,654	42	330	8,026

[1] Fish put in holding tanks as captured, then tagged and released.

[2] Fish brought aboard, immediately tagged and released.

[3] Fish tagged and treated with oxygen.

* Includes 240 fish tagged and released from the *Commander*.

32). All releases from June 22 through July 2, the last date of tagging, were east of 165°W long. and mainly in Bristol Bay. These two groups are designated hereinafter as "offshore" and "inshore", respectively.

Table 8 gives specific release data for each vessel; for later reference herein, this table also enumerates tag recoveries. All releases and recoveries listed are of sockeye salmon. By vessel, 841 tagged sockeye were released from the *Kelez*, 6,945 from the *Yaquina*, and 240 from the *Commander*, for a total of 8,026.

In Table 9 is a summary by release group, type of gear by which sockeye were captured for tagging and physiological studies, type of tag or tags applied, and the method by which fish were handled after capture. A later section entitled "Preliminary analysis of recovery rates" contains material relating to all items in Table 9 except the "Oxygen treatment"; the latter is described under "Physiology" in the section entitled "Work in progress".

In addition to measuring fork lengths and collecting scales of tagged fish, the tagger recorded a number from 1 to 5 for each fish to summarize his judgment of its physical condition (degrees of scale loss, injury, and general vigor). The number of seconds out of water during tagging by the "standard treatment" of Table 9 was recorded for 126 releases from the *Yaquina.* (Additional data taken for physiological studies are described later.)

Recovery of Tags

The tagging experiment was publicized before and during the fishing season in Bristol Bay. At the time tags were released, four out of five were designated from the serial numbers as worth a reward of $3 if recovered; one out of five was worth a reward of $15 if recovered. The Fisheries Research Institute of the University of Washington, the Fisheries Research Board of Canada, and the Japanese Fishery Agency increased their basic reward from $1 to $3.

The Alaska Department of Fish and Game assisted in the recovery of tags; that agency and the Fisheries Research Institute of the University of Washington forwarded tags recovered on the spawning grounds. Cannery superintendents provided space for holding and collecting data on whole fish; they also designated tag processors who recorded (along with finders' names and addresses) the recovery dates and areas for tagged fish submitted by fishermen and cannery personnel.

Detailed biological data from individual recoveries are not yet available in convenient format. However, Table 8 lists by area and tag release the number of recoveries reported to the Seattle Biological Laboratory through November 15, 1965.

Preliminary Analysis of Tag Recoveries

Detailed fishery statistics and biological data from the 1965 return to Bristol Bay are not yet available. These will be required for final interpretation of our progress toward objectives. The present section contains a few preliminary analyses.

Offshore and Inshore Tagging

The offshore release of 4,998 fish yielded 338 recoveries, or seven percent; the inshore release of 3,028 fish yielded 837 recoveries, or 28 percent (Tables 8 and 9). The much lower rate of recovery from the offshore releases may be caused by factors acting singly or in combination. Grossly, these are: (1) differential escapement of survivors through the Bristol Bay fishery, as would occur because of different times of arrival; (2) unequal racial composition of offshore and inshore releases; (3) appreciable natural mortality between the dates of offshore and inshore releases; (4) a high rate of tag failure operating for a longer period on the offshore releases; (5) higher mortality on the offshore release from the immediate or delayed effects of capture and tagging; and (6) selective predation of tagged fish operating longer on the offshore release.

Types of Fishing Gear

Longlines, purse seines, and gillnets were used to capture fish for tagging and physiological studies (see Table 8). In Table 10 is a comparison of recovery rates by type of gear.

Table 10. Comparison of recovery rates of sockeye salmon tagged after capture by longlines, gillnets, and purse seines, offshore and inshore (data from Table 8).

Group and gear	Number released	Number recovered	Percent recovered
Offshore			
Longline	240	14	5.8
Gillnet	378	0	0.0
Purse seine	4,380	324	7.4
Sub-total	4,998	338	6.8
Inshore			
Longline	80	23	28.8
Gillnet	233	16	6.9
Purse seine	2,715	798	29.4
Sub-total	3,028	837	27.6
Total	8,026	1,175	14.6

Results in Table 10 agree with the observation that salmon taken at sea by gillnets are less likely to survive after tagging than if taken by longlines and purse seines (Hartt, 1963).

Certain of the release and recovery data of Table 8, in contrast with the pooled data of Table 10, provide comparisons among three types of gear. It is assumed that these releases are essentially free of differences in racial composition and times of arrival in the Bristol Bay fishery. For example, the inshore tagging from gillnets on June 30 yielded a recovery rate of 14 percent; nearby tagging from a purse seine led to a recovery rate of 22 percent. Inshore releases from longlining and seining on June 26 led to respective recovery rates of 28 and 34 percent. Finally, offshore tagging from longlines and purse seines on June 10–12 yielded recovery rates of five and six percent. No recoveries were made of fish caught offshore in gillnets, whereas 7.4 percent of the fish caught in purse seines were recovered.

We were interested in comparing offshore and inshore recovery rates on maturing sockeye salmon in connection with the work of Taguchi (1961) and Parker (1959, 1963) mentioned previously. There were 16 recoveries from 233 sockeye salmon tagged after capture in gillnets inshore, but no recoveries from 378 releases offshore (Table 10). Aside from possible differences in racial composition and of arrival times of survivors in the Bristol Bay fishery, however, this comparison is not of itself too informative.

The 16 recoveries were from the inshore release of June 30 (set K-19); an additional release of 120 fish taken by gillnets inshore yielded no recoveries. The pertinent result is the absence of recoveries of fish caught in gillnets and released either offshore *or* inshore, except for the recoveries from set K-19.

Only in set K-19 were gillnets used specifically to take fish for tagging; in all others, fish were gradually accumulated in the holding tanks as nets were hauled for the dropout study. Average times that tagged fish had fought the gear were estimated from average fishing time of nets in the two situations. The average time between setting and lifting was 4.1 hours for sets in the dropout study, and 2.4 hours for set K-19. Therefore, time spent fighting the gear may be a dominant factor in the survival of salmon tagged at sea from gillnets.

Types of Tags

Recovery rates of disc, spaghetti, and double tags were compared (Table 11). Disc tags were affixed anterior, and spaghetti tags posterior, to the dorsal fin. These positions were retained in double tagging. The recovery rates for disc tags were higher than for spaghetti tags for all sets (Y-29, Y-35, and Y-36) in which the two types were compared. These results agree with the observation of Hartt (1963) that disc tags have yielded recovery rates almost double those of spaghetti tags in the year of tagging. Pooled data from the three sets show that the percentage of disc tags recovered was nearly twice that of spaghetti tags. This difference in recovery rates may be due to gear selection of disc tags, differential reportability, tagging mortality, tag loss, or a combination of these factors. Since three of the 10 double-tagged fish recovered from sets Y-24 and Y-27 were without the spaghetti tag, the present experiment provides some evidence of differential tag loss.

The results of set Y-27 suggest differential tag mortality. Since one can reasonably assume no difference in gear selection, and a reportability for double tags at least as high as that for disc tags, the higher recovery rate for disc tags may reflect a lower survival of double-tagged fish.

Further and more specialized experiments with single and double tags must be conducted before the separate factors of reportability, tag loss, tagging mortality, and tag selectivity can be accurately assessed.

Standard and Delayed Tagging

During "standard" tagging (Table 9), fish were placed in holding tanks at the time of capture, then tagged and released several hours later. During "immediate" tagging, fish were tagged and released immediately, while the gear was being hauled.

Of 110 sockeye salmon caught on longlines (set K-6 of Table 8), 35 were tagged by the "immediate" treatment and the remaining 75 by the "standard" treatment. Respective recovery rates were 12 and 0 percent. Of seven fish taken on longlines and tagged by the "immediate" treatment (set K-7), two (29 percent) were recovered (the highest recovery rate observed for any offshore release). Of 33 fish taken on longlines and released after "standard" tagging (set K-5), only one was recovered (three percent). The data from longline tagging suggest that immediate release results in increased survival.

Effect of Holding Tanks on Survival

A significant difference in recovery rates between fish held in the port and starboard compartments of a holding tank was reported by Hartt (1963). The difference was believed due to a difference in oxygen content between the compartment with the inlet and the compartment without.

To alleviate this condition on the *Yaquina*, a flexible inlet hose was used which was changed from side to side at about 20-minute intervals. To check the effectiveness of this procedure, the recovery rates of fish held before tagging in the port and starboard compartments were tested by Chi-square. In 26 separate sets the tests indicated significant differences in only two sets, and it was concluded that no difference in water quality existed between compartments. It was possible, however, that the water quality within the tank may have adversely affected the survival of the tagged fish.

To test this possibility some fish were tagged di-

TABLE 11. Comparison of recovery rates of disc, spaghetti, and double tags.

Set number	Number tagged			Number recovered			Percent recovered		
	Disc	Spaghetti	Disc and Spaghetti	Disc	Spaghetti	Disc and Spaghetti	Disc	Spaghetti	Disc and Spaghetti
Y 24	—	7	29	—	—	5	—	—	17
Y 27	201	—	24	70	—	5	35	—	21
Y 29	112	45	—	29	9	—	26	20	—
Y 35	228	100	—	89	16	—	39	16	—
Y 36	155	53	—	63	13	—	41	24	—

rectly from the seine, whereas others were held in the tanks prior to tagging. Experimenting with four separate sets, the recovery rates were higher from fish held in the tanks for two sets, the rates were the same for one set, and for another the recovery rate of fish held in the seine was the higher. The available evidence, therefore, does not indicate a factor within the tank itself that would confound other comparisons.

Effect of Crowding

An estimated 5,000 fish were taken in two inshore seine hauls by the *Yaquina* on June 30 (sets Y-31 and Y-32, Table 8). Most of these were released untagged; some were in evident distress.

From 17 offshore sets by the same vessel in which the release numbers accurately reflected the total catches, and therefore the degree of crowding, a negative correlation ($r = -.357$) was found between recovery rate and number of tagged fish released; although not significant at the 95 percent level, its direction suggests the same harmful effect of crowding noted by Hartt (1963). The true effect of crowding is obscured by changes in weather, different exploitation rates in Bristol Bay on fish tagged on different dates, and other factors.

Time Required for Tagging

We have long suspected that the time required for tagging may reach a point critical to the survival of tagged fish. Therefore, in 1964, the time required to tag 50 fish captured in two sets was recorded (Lander *et al.*, 1966). These data indicated a decline in the rate of recovery as tagging time approached 30 seconds. The experiment was repeated in 1965, when 126 tagging times were recorded (during set Y-21). Again, reduced recovery rates with increasing time were indicated. Further study of this effect is planned.

WORK IN PROGRESS

Mortality

The Alaska Department of Fish and Game is compiling detailed catch, effort, management, and biological statistics needed before the feasibility of estimating terminal natural mortality by tagging can be determined. When these data are available, all material will be analyzed to determine whether a realistic mathematical model can be developed from 1965 data. Additional tagging on this stock is tentatively planned for 1966.

Growth

Biological data collected at times of release and recovery during 1965 permit a study of short-term ocean growth of Bristol Bay sockeye. Results will be of interest because previous work on ocean growth of Bristol Bay sockeye was based on successive sampling of the stock at sea, and terminated three weeks before the peak return (Lander and Tanonaka, 1964). Preliminary analysis of tagging data, however, suggests the need for improved quality of release and recovery information.

Physiology

Objectives of the physiology field study were: (1) to characterize both exhausted and rested fish biochemically; (2) to test the hypothesis that biochemical responses and hence the sensitivity of fish to tagging are different at early and full maturity; and (3) to test the hypothesis that holding tagged fish in water supersaturated with oxygen before release will enhance survival as measured by the recovery of tags.

For objectives (1) and (2) above, samples of blood, muscle, and liver were fixed in 10 percent trichlorocetic acid (TCA), then frozen for later laboratory analyses of glucose (or glycogen), lactate, and pyruvate. Serum was separated from blood; both fractions were frozen for later determinations of adrenal corticosteroids and urea, and of chloride, phosphate, potassium, and sodium ions. Of 250 fish sampled, about half were sampled soon after capture and the rest after 24 or more hours in holding tanks. Blood *p*H was determined electrometrically on 65 of these fish while alive; precautions were taken to keep the electrode chamber at the same temperature as the sea water to avoid exposure of blood samples to the air, and to standardize the instrument frequently. Bouin-fixed subsamples of adrenal and pituitary glands were taken for histological study.

Preliminary tests with fingerling sockeye salmon in a plastic oxygen-pressure chamber (Fig. 33) had suggested that 3X supersaturation in water greatly increased survival after complete exhaustion. A 500-gallon tank was accordingly fabricated and welded in place near holding tanks aboard the *Kelez* (Fig. 34). Adult salmon captured by gillnets and longlines and tagged were alternately released and put in the tank. Water was recirculated inside the tank continuously during and after loading. After 30 to 50 salmon had been placed in the tank, 50 gallons of sea water were drained from the full tank by displacement with pure oxygen. The tank was tightly sealed, and oxygen pressure was raised to 30 PSI above atmospheric pressure. Pressure was released after about 60 minutes at 3X supersaturation (as measured by a silver-lead electrode in the bottom of the tank). Fish were released by tripping an end hatch abutting a flume

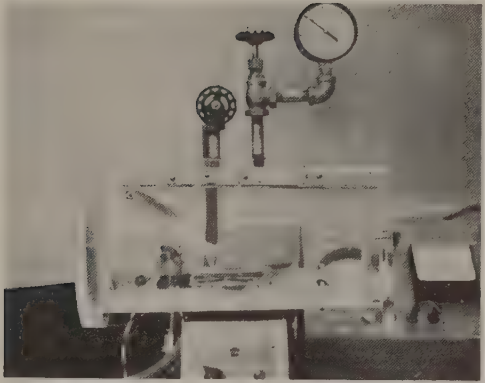

Figure 33. Plastic pressure chamber, pilot model. Stirring by magnetic bar assures proper function of oxygen electrode and accelerates dissolution of oxygen.

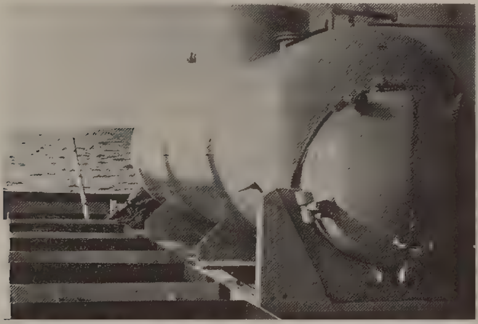

Figure 34. Holding tanks (lower left) and oxygen pressure tank aboard the RV *George B. Kelez.* Access door at top center. Three viewing ports are not visible.

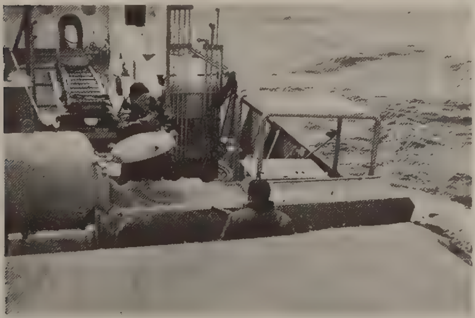

Figure 35. Emptying tank contents after release of oxygen pressure.

which carried fish and water directly over the side of the vessel (Fig. 35). Although interpretation is tenuous because of generally poor tag recoveries, there was no evidence of increased survival.

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SEROLOGY

by Fred Utter

The objectives of the serological studies which have been conducted under the International North Pacific Fisheries Commission's research program include the separation of major Pacific salmon stocks which intermingle on the high seas and the detection of the onset of maturity in Pacific salmon. During the past year our racial studies have focused on chum and pink salmon, and the major emphasis of our maturity work has been on sockeye salmon.

Blood Group Studies of Pink and Chum Salmon

More than 60 rainbow trout isoimmune reagents were tested for cross-reactivity with chum or pink salmon red blood cells; of these, 16 cross-reacted with chum salmon and 12 cross-reacted with pink salmon cells. The reagents with strong reactions were diluted serially until they no longer reacted with any of the test cells. Where differences of two or more serial dilutions were found for test cells of a given species, cells from individuals which failed to react at the lower dilution were used for absorptions.

Table 12 lists the reaction frequencies of chum salmon cells from Puget Sound and Alaskan areas with two of the isoimmune reagents. The reactive frequency of reagent 252 with cells from three of the four areas of the Puget Sound and Columbia River district exceeded 50 percent, whereas all of the Alaskan samples reacted with a frequency considerably below 50 percent. The limited testing with reagent 425 indicates a possible value of this reagent for separation of Puget Sound chum salmon from those originating in Alaskan waters. All of the Quilcene River chum salmon cells which were tested with reagent 425 reacted, whereas the highest reactive frequency of cells from Alaskan areas was 54.5 percent.

The reactions of pink salmon cells from various Alaskan and Canadian areas with two rainbow trout isoimmune reagents are given in Table 13. A pool of reagent 425 which had been absorbed with weakly reacting pink salmon red cells reacted at a higher frequency with cells from the three southernmost areas. Further work with this reagent may provide a means of separation of pink salmon over a broad geographic range. Although reagent 417 was tested with cells from only three areas, the distinct frequency difference between two adjacent areas, Kachemak Bay in Cook Inlet and Olsen Creek in Prince William Sound, suggests that this reagent may be useful in discriminating stocks originating within a more limited geographic area.

Serological Studies of Maturity in Sockeye Salmon

Female sockeye salmon taken on the high seas during the fall and winter cruises of the RV *George B. Kelez* were tested for the presence of the SM (serum maturity) factor (Ridgway, 1961). The SM factor has been characterized as the vitellin component of

Table 12. Reactions of red blood cells from chum salmon from various American areas with two rainbow trout isoimmune sera.

		Reagent							
		252 (pool of numerous bleedings)				425 (August 1964 bleeding)			
Area	Year	No. positive	No. negative	Total sample	Percent positive	No. positive	No. negative	Total sample	Percent positive
Washington & Oregon									
Columbia R.	1964	15	14	29	51.7	—	—	—	—
Samish R.	1964	9	6	15	60.0	—	—	—	—
Skagit R.	1964	16	1	17	94.1	—	—	—	—
Quilcene R.	1964	7	17	24	29.1	10	0	10	100
Alaska									
Tutka Bay	1965	0	13	13	0	5	8	13	38.4
Olsen Creek	1965	5	17	22	22.7	12	16	22	54.5
Annette I.	1964	1	29	30	3.3	—	—	—	—
Annette I.	1965	9	15	24	37.5	6	18	24	25.0
Chi-square value			55.4**					16.8**	

** Significant at 1-percent level.

Table 13. Reactions of pink salmon red blood cells from Canadian and Alaskan areas with two rainbow trout isoimmune sera.

		Reagent							
		425 (Pool absorbed)				417 (Pool)			
Area	Year	No. positive	No. negative	Total sample	Percent positive	No. positive	No. negative	Total sample	Percent positive
Canada & S.E. Alaska									
Skeena R.	1964	22	0	22	100	—	—	—	—
Annette I.	1964	27	2	29	93.1	—	—	—	—
Annette I.	1965	16	0	16	100	6	8	14	42.9
Prince William Sound & Cook Inlet									
Kachemak Bay	1965	11	8	19	57.8	16	3	19	84.2
Sheep Bay	1964	22	3	25	88.0	—	—	—	—
Olsen Creek	1965	12	8	20	60.0	6	12	18	33.3
Homer	1964	19	5	24	79.1	—	—	—	—
Chi-square value			26.6**				10.1**		

** Significant at 1-percent level.

Table 14. Frequency of occurrence of positive SM reactions among 488 female sockeye salmon taken during the fall 1964 and winter 1965 cruises of the RV *George B. Kelez*, according to the numbers of winters spent at sea.

	September-October			February-March		
		SM-positive			SM-positive	
Number of winters at sea	Number tested	Number	Percentage	Number tested	Number	Percentage
0	2	0	0.0	47	1	2.1
1	223	6	2.7	59	48	81.4
2	60	31	51.7	90	89	98.9
3	0	0	0.0	7	7	100.0

the developing egg (Ridgway *et al.*, 1962; Vanstone and Ho, 1961). Its presence is therefore considered a valid indication that the fish is female and is maturing.

Table 14 summarizes the reaction data for the SM factor with reference to the number of winters at sea for 488 female sockeye salmon. These data have been plotted in Figure 36 as the percentage of SM-positive females in the different winter-at-sea categories. Females which have spent two winters at sea apparently mature earlier than those that have spent only one winter.

We have continued to seek an immunological method for detection of the onset of maturity in males as well as more sensitive methods for detection of maturity in females. We are currently working on a method of hormonal assay which has proven valuable for detection of various antigenic hormones in higher vertebrates (Wide and Gemzell, 1960; Berson *et al.*, 1963). Three rabbits have been immunized with a purified salmon pituitary preparation furnished by Dr. H.L.A. Tarr and associates at the Fisheries Research Board of Canada's Technological Station in Vancouver, B.C. Concurrently we have been working on methods of sensitizing various mammalian and avian erythrocytes so that they may be capable of

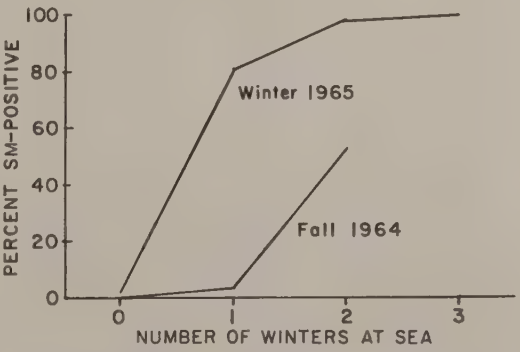

Figure 36. Percentage of SM positive female sockeye salmon taken in the fall 1964 and winter 1965 cruises of the RV *George B. Kelez* at different ocean ages.

absorbing gonadotropic hormones which may be present in salmon sera. If the gonadotropic hormone adhering to the sensitized erythrocyte reacts with a specific antiserum, the resulting agglutination would be an indication of the onset of maturity in either male or female salmon. Such a test would be much more sensitive than the double-diffusion test currently used for the detection of the SM factor.

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SOCKEYE SALMON SCALE STUDIES

by James E. Mason

This report presents the results of classifying to continent of origin the mature and immature sockeye salmon caught on the high seas in 1962, plus the mature salmon in the 1964 Bristol Bay inshore samples. Mason (1966) reported on the analysis of 1963 samples. Samples collected in 1964 from the high seas and from Asia were not available for analysis.

The three scale characters used to determine the continent of origin of both mature and immature sockeye salmon were defined by Anas (1964) as follows: (1) Circulus count within the first half of the width[2] of the first-ocean zone. (2) The scale width measured across the first six circuli in the first-ocean zone. (3) The scale width measured across circuli 13–18 inclusive in the first-ocean zone.

The following material will be presented in this report: the criteria used for determining maturity, the sources of the samples, the method of interpreting the scale characters, the classification procedures, and the results of classifying sockeye to continent of origin. Since the classification procedures for mature and immature sockeye salmon were different, the procedure for classifying mature fish will be described first, followed by the procedure for immature sockeye.

MATURITY

Sockeye salmon samples collected on the high seas were classified as mature if the gonad weights in grams exceeded the following values:

	Females	*Males*
Late May	15.0	1.0
Early June	15.0	2.0
Middle and late June	20.0	3.0
Early July	25.0	3.0
Middle and late July	25.0	5.0

These criteria are from a letter dated April 2, 1964, from the Chief of the Research Section of the Fisheries Agency of Japan to the Executive Director of the INPFC Secretariat.

SAMPLES

Bristol Bay samples taken from the Branch, Egegik, Kvichak, Naknek, Ugashik, and Wood Rivers (approximately at the peak of the respective runs) were used as North American standard reference samples for 1962 and 1964. Because no samples from inshore areas of Kamchatka or the Okhotsk Sea were available for 1962 and 1964, two samples collected June 12, 1962, near 49°N lat., 166°E long., were used as Asian standards and for estimating the average error of misclassification for 1962. They are shown as samples 1 and 2 in Table 15. The date and location of collection indicated that the fish were not from North America; most probably they originated on the Kamchatka Peninsula. These same samples were used by Landrum and Dark (1964) in the morphological classification of maturing sockeye salmon in 1962.

The 1962 samples of mature and immature sockeye salmon caught on the high seas were mainly collected aboard the Japanese motherships *Meisei Maru*, *Shinano Maru*, *Miyajima Maru*, and *Jinyo Maru*. Samples were also collected by the U.S. research vessels *George B. Kelez* and *Bertha Ann*.

Only the samples which exceeded 29 mature or 17 immature sockeye salmon were used.

INTERPRETATION OF SCALE CHARACTERS

The scale character data presented for 1962 through 1964 were collected by the same personnel using the same equipment, procedures, and criteria as in previous years (Anas, 1963; Anas and Murai, MS 1964). Only the " preferred " scale located two rows above the lateral line on the diagonal scale column which extends downward from the posterior insertion of the

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[2] " Width " is substituted for " length " as used by Anas (1963, 1964) and Anas and Murai (MS 1964).

Table 15. Classification of high seas samples of mature sockeye salmon in 1962.

Sample number	Sampling date	Sampling location[1]		Sample size	Number of Bristol Bay sockeye	Percent classified		Corrected percent Bristol Bay type	90% confidence interval[2]
		Lat. (N)	Long.			Bristol Bay type	Kamchatkan type		
1**	6/12	49—35	166—26 E	73	21	28.77	71.23	—	—
2**	6/12	49—22	166—36 E	88	22	25.00	75.00	—	—
3	5/25	46—17	169—53 E	167	107	64.07	35.93	65	55—76
4	5/27	47—17	170—17 E	57	14	24.56	75.54	0	0—17
5	5/26	47—00	170—00 E	50	13	26.00	74.00	0	0—18
6	5/25	47—23	169—20 E	87	17	19.54	80.46	0	0—14
7	5/26	47—00	169—00 E	52	22	42.31	57.69	27	7—47
8	5/27	47—03	169—25 E	51	9	17.65	82.35	0	0—18
9	6/18	48—26	167—48 E	83	28	33.73	66.27	12	0—27
10	6/18	48—26	167—58 E	91	28	30.77	69.23	7	0—21
11	6/12	48—20	168—12 E	92	27	29.35	70.65	5	0—18
12	6/10	48—10	168—23 E	47	12	25.53	74.47	0	0—19
13	6/10	48—45	168—44 E	50	8	16.00	84.00	0	0—18
14	6/14	48—44	168—44 E	48	11	22.92	77.08	0	0—18
15	6/16	48—44	168—44 E	48	13	27.08	72.92	7	0—19
16	6/16	48—35	169—14 E	43	9	20.93	79.07	0	0—19
17	6/12	48—32	167—41 E	101	30	29.70	70.30	5	0—18
18	6/14	48—32	168—23 E	54	13	24.07	75.93	0	0—17
19	7/3	50—10	165—31 E	43	14	32.56	67.44	10	0—31
20	6/21	49—38	166—31 E	48	12	25.00	75.00	0	0—18
21	6/29	50—09	168—28 E	38	15	29.47	60.53	22	0—45
22	6/23	50—13	169—17 E	51	13	25.49	74.51	0	0—18
23	6/23	50—13	169—34 E	41	12	29.27	70.73	4	0—25
24	6/25	50—20	170—18 E	36	16	44.44	55.56	31	7—55
25	6/10	50—23	171—18 E	127	52	40.94	59.06	25	12—38
26	6/2	50—09	179—37 E	122	61	50.00	50.00	41	28—54
27	5/31	51—14	175—22W	184	140	76.09	23.91	86	77—95
28	6/1	51—08	175—15W	55	40	72.73	27.27	80	63—98
29	5/31	51—22	176—04W	178	133	74.72	25.28	84	75—93
30	6/1	51—20	176—00W	49	38	77.55	22.45	89	72—100
31	6/2	51—19	175—51W	54	41	75.93	24.07	86	69—100
32	6/4	51—08	175—53W	109	89	81.65	18.35	96	85—100
33	6/11	50—57	176—00W	47	34	72.34	27.66	80	61—99
34	6/2	51—08	176—45W	57	43	75.44	24.56	85	69—100
35	6/6	51—20	176—57 E	189	160	84.66	15.34	100	92—100
36	6/7	51—20	176—09 E	51	40	78.43	21.57	38	18—58
37	6/6	51—20	176—21 E	97	84	86.60	13.40	100	89—100
38	6/5	51—00	176—00 E	37	22	59.46	40.54	57	34—80
39	6/7	51—09	174—23 E	51	35	68.63	31.37	73	55—92
40	6/4	51—28	173—01 E	30	25	83.33	16.67	99	79—100
41	6/25	51—10	170—41 E	33	14	42.42	57.58	28	3—52
42	6/27	51—02	170—36 E	44	10	22.73	77.27	0	0—19
43	6/27	51—06	171—01 E	35	9	25.71	74.29	0	0—22
44	6/28	50—53	171—11 E	33	12	36.36	63.64	17	0—41
45	6/3	51—00	170—00 E	66	23	34.85	65.15	14	0—31
46	6/25	50—32	169—15 E	44	14	31.82	68.18	9	0—29
47	7/1	55—33	165—30 E	36	14	38.89	61.11	21	0—45
48	7/5	55—33	165—41 E	31	10	32.26	67.74	10	0—34
49	7/1	50—45	166—00 E	42	9	21.43	78.57	0	0—20

Continued . . .

Table 15. (Continued).

Sample number	Sampling date	Sampling location[1]		Sample size	Number of Bristol Bay sockeye	Percent classified		Corrected percent Bristol Bay type	90% confidence interval[2]
		Lat. (N)	Long.			Bristol Bay type	Kamchatkan type		
50	7/5	50—42	165—59 E	30	9	30.00	70.00	6	0—30
51	5/25	52—31	170—23 E	77	33	42.86	57.14	28	12—44
52	6/1	52—00	170—12 E	46	13	28.26	71.74	3	0—22
53	6/19	53—28	175—57W	30	23	76.67	23.33	87	65—100
54	5/25	52—30	170—23 E	76	25	32.89	67.11	11	0—26
55	6/16	53—18	166—55 E	137	37	27.01	72.99	0	0—14
56	6/16	54—01	177—01W	54	49	90.74	9.26	100	86—100
57	6/12	47—14	160—59 E	52	11	21.13	78.85	0	0—18
58	6/11	812		55	14	25.45	74.55	0	0—17
59	6/12	49—33	176—45 E	148	41	47.70	42.30	2	0—12
60	6/17	812		45	7	15.56	84.44	0	0—19
61	6/18	812		146	42	28.77	72.23	4	0—14
62	6/13	813		45	12	26.67	73.33	0	0—19
63	6/19	947		107	25	23.36	76.64	0	0—12
64	6/11	945		53	17	32.08	67.92	9	0—28
65	6/12	945		81	31	38.27	61.73	20	5—36
66	6/13	945		46	16	34.78	65.22	14	0—34
67	6/15	944		100	42	42.00	58.00	79	66—92
68	6/17	944		39	8	20.51	79.49	0	0—20
69	5/25	1003		151	87	47.62	42.38	54	42—66
70	5/31	1006		81	42	51.85	48.15	44	28—60
71	6/6	1008		90	35	38.89	61.11	21	6—36
72	6/6	1009		136	86	63.24	36.76	64	52—76
73	5/31	1123		64	44	68.75	31.25	74	57—90
74	6/6	1121		91	80	87.91	12.09	100	89—100
75	6/6	1120		67	48	71.64	28.36	79	63—94
76	6/1	1115		81	63	77.78	22.22	89	76—100
77	6/1	1116		74	62	83.78	16.22	100	88—100
78	7/13	50—56	163—10 E	32	15	46.88	53.12	0	0—22
79	7/9	50—32	163—32 E	42	16	38.10	61.90	0	0—20
80	7/9	50—44	163—32 E	48	8	16.67	83.33	0	0—18
81	7/11	50—20	163—32 E	33	9	27.27	72.73	1	0—23

[1] Numbers other than longitude and latitude refer to area designation 1° of latitude by 1° of longitude (Lander and Tanonaka, 1964).

[2] Truncated at 0 percent and 100 percent.

** Asian standards.

dorsal fin, or a scale from the " A " zone (page 115, INPFC 1961 Annual Report) was read.

Classification Procedures for Mature Sockeye Salmon

The discriminant function computed by Anas and Murai (MS 1964) for the 1957 scale-character data was used to determine the percentages of specimens classified as Bristol Bay type sockeye salmon in the 1962 high seas samples of mature sockeye and in the 1962 and 1964 inshore samples. The observed percentages of misclassified specimens in 1962 and 1964 in the Bristol Bay stream samples were weighted by their respective escapement estimates shown in Tables 16 and 17. The computed average error of misclassification of Bristol Bay type sockeye salmon was 16.1 percent in 1962 and 20.8 percent in 1964. The corrected percentage of Bristol Bay type sockeye salmon in the 81 samples of mature sockeye caught on the high seas in 1962 and the 90-percent confidence intervals, computed by the procedures of Anas and Murai (MS 1964), are given in Table 15.

Discriminant function analysis by use of the three defined characters has separated Bristol Bay and Asian samples in all years from 1956 through 1963 (Fig. 37). In 1964, results of the classification of sockeye salmon from Bristol Bay rivers were similar to those of other years.

Table 16. Average error in misclassification weighted according to relative abundance of the contributing stocks of Bristol Bay sockeye salmon in 1962.

River	Escapement in millions	Relative abundance	Observed percent of misclassification	Weighted value
Branch	0.091	0.0164	11.8	0.1935
Egegik	1.027	0.1851	10.3	1.9065
Kvichak	2.581	0.4650	12.1	5.6265
Naknek	0.722	0.1301	7.9	1.0278
Ugashik	0.255	0.0459	23.2	1.0649
Wood	0.874	0.1575	40.0	6.3000
Total	5.550	1.0000		16.1192

Average errors of misclassification were 16.1192 percent for the Bristol Bay population and 26.7081 percent for the Kamchatkan population (samples 1 and 2, Table 15).

Table 17. Average error in misclassification weighted according to relative abundance of the contributing stocks of Bristol Bay sockeye salmon in 1964.

River	Escapement in millions	Relative abundance	Observed percent of misclassification	Weighted value
Branch	0.249	0.0502	10.7477	0.5395
Egegik	0.850	0.1715	1.6949	0.2907
Kvichak	0.957	0.1932	37.3219	7.2106
Naknek	1.350	0.2725	5.5319	1.5074
Ugashik	0.473	0.0954	20.7756	1.9820
Wood	1.076	0.2172	42.5466	9.2411
Total	4.954	1.0000		20.7713

Average error of misclassification was 20.7713 percent for the Bristol Bay population; 1964 samples for the Kamchatkan population are not currently available.

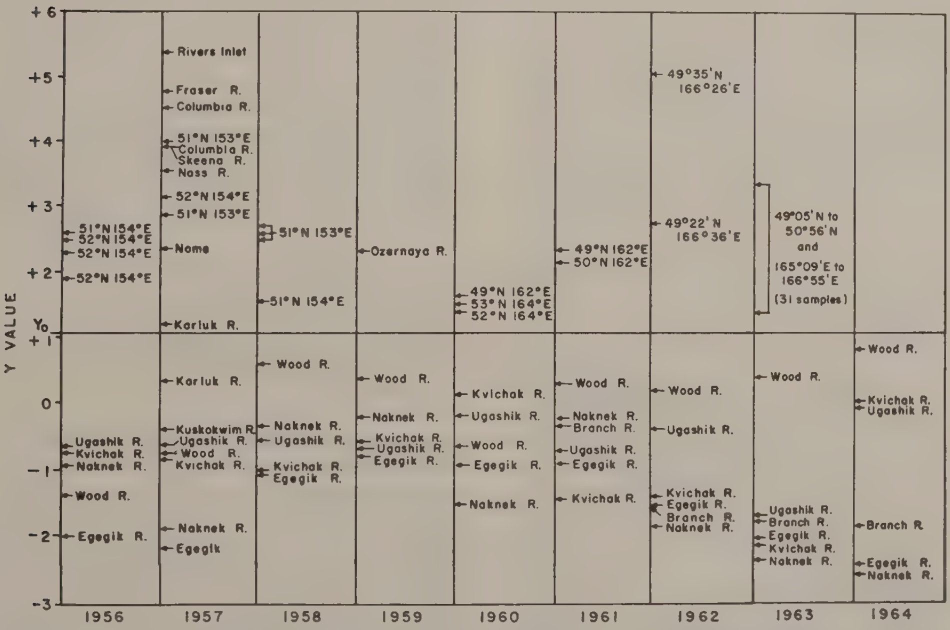

Figure 37. Linear distribution of sample mean "Y" values; three scale characters and a discriminant function computed from data collected in 1957 were used.

Classification of Mature Sockeye Salmon in North Pacific Ocean Samples in 1962

Samples taken May 21-31, 1962, between longs. 165°30′E and 170°30′E (Fig. 38)

South of lat. 49°30′N. In four of six samples, sockeye salmon were classified as 100 percent Kamchatkan type. Sockeye salmon in two samples (3, 7) were classified as 65 and 27 percent Bristol Bay type. The 90-percent confidence intervals for the latter two samples excluded zero.

North of lat. 49°39′N. The sockeye salmon in two samples (51, 54) were classified as 28 and 11 percent Bristol Bay type. The 90-percent confidence interval for sample 51 was 12–44 percent; thus, it is probable that Bristol Bay sockeye occurred in this area at this time of the year.

Samples taken May 21–31, 1962, between longs. 170°30′E, and 175°30′E (Fig. 38)

North of lat. 49°30′N. All three samples included Bristol Bay type sockeye salmon; the percentages ranged from 44 to 74 percent. The 90-percent confidence intervals all excluded zero. These high percentages were attributed to the presence of Bristol Bay sockeye, not sampling variation.

Samples taken June 1–10, 1962, between longs. 165°30′E and 170°30′E (Fig. 39)

South of lat. 49°30′N. The sockeye salmon in two samples (12, 13) were classified as 100 percent Kamchatkan type.

North of lat. 49°30′N. Two samples (45, 52) showed small percentages of Bristol Bay type sockeye salmon. Since the 90-percent confidence intervals included zero, it is possible that the point estimates reflected variation in sampling.

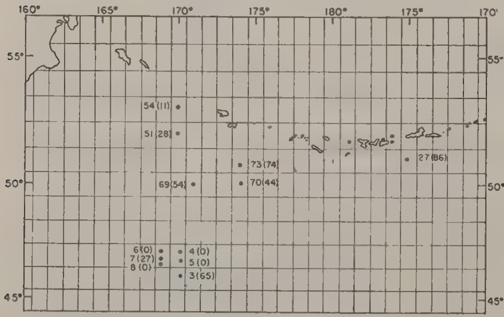

FIGURE 38. Samples of maturing sockeye salmon taken May 21–31, 1962, showing percentage of Bristol Bay type sockeye salmon by 1° × 1° areas. First number is the sample number; second number (in parentheses) indicates percentage Bristol Bay type sockeye.

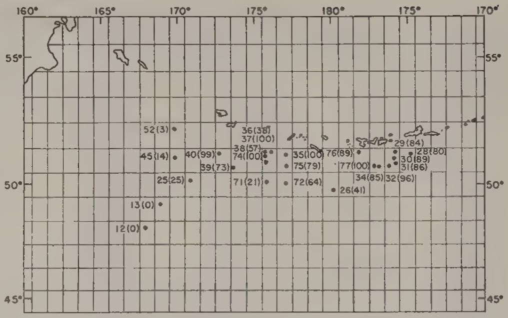

FIGURE 39. Samples of maturing sockeye salmon taken June 1–10, 1962, showing percentage of Bristol Bay type sockeye salmon by 1° × 1° areas. First number is the sample number; second number (in parentheses) indicates percentage Bristol Bay type sockeye.

Samples taken June 1–10, 1962, between longs. 170°30′E and 175°30′E (Fig. 39)

North of lat. 49°30′N. The sockeye salmon in three samples (25, 39, 40) were classified from 25 to 99 percent Bristol Bay type; all 90-percent confidence intervals excluded zero. Samples collected north of lat. 50°30′N had higher percentages of Bristol Bay salmon than those collected to the south.

Samples taken June 1–10, 1962, between longs. 175°30′E and 179°30′W (Fig. 39)

North of lat. 49°30′N. All samples were classified from 21 to 100 percent Bristol Bay type sockeye salmon; all 90-percent confidence intervals excluded zero. The samples with the highest percentages of Bristol Bay salmon were near the Aleutian Islands.

Samples taken June 1–10, 1962, between longs. 179°30′W and 174°30′W (Fig. 39)

North of lat. 49°30′N. All samples were classified from 80 to 100 percent Bristol Bay type sockeye salmon; 90-percent confidence intervals ranged from 52 to 100 percent.

Samples taken June 11–20, 1962, between longs. 165°30′E and 170°30′E (Fig. 40)

South of lat. 49°30′N. Eighteen of 20 samples were classified as less than 20 percent Bristol Bay type sockeye salmon. The average was about eight percent. The 90-percent confidence intervals included zero except for samples 65 and 67 which classified 20 and 79 percent Bristol Bay type; confidence intervals were 5–36 percent and 66–92 percent, respectively.

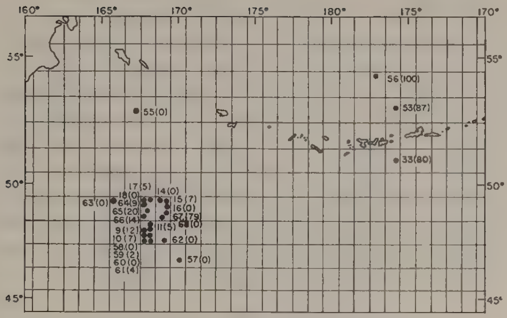

FIGURE 40. Samples of maturing sockeye salmon taken June 11–20, 1962, showing percentage of Bristol Bay type sockeye salmon by 1° × 1° areas. First number is the sample number; second number (in parentheses) indicates percentage Bristol Bay type sockeye.

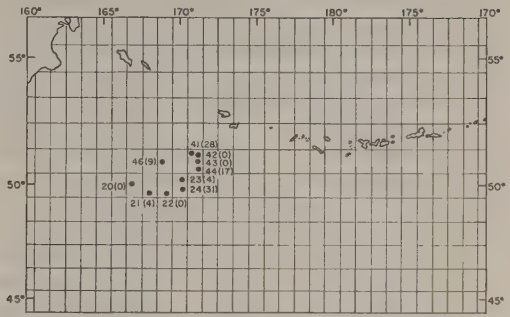

FIGURE 41. Samples of maturing sockeye salmon taken June 21–30, 1962, showing percentage of Bristol Bay type sockeye salmon by 1° × 1° areas. First number is the sample number, second number (in parentheses) indicates percentage Bristol Bay type sockeye.

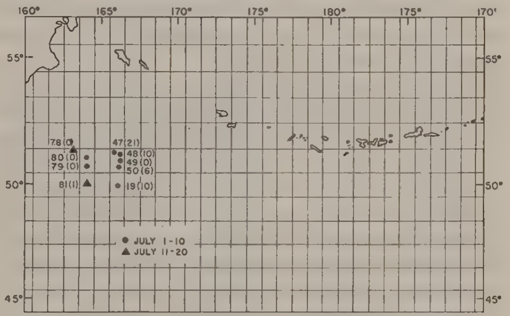

FIGURE 42. Samples of maturing sockeye salmon taken July 1–20, 1962, showing percentage of Bristol Bay type sockeye salmon by 1° × 1° areas. First number is the sample number, second number (in parentheses) indicates percentage Bristol Bay type sockeye.

Samples taken June 11–20, 1962, between longs. 179°30′ W and 174°30′ W (Fig. 40)

Only two samples (53, 56) from the Bering Sea and one (33) from south of the Aleutian Island chain were available. All showed high percentages (80–100) of Bristol Bay type sockeye salmon, and all had 90-percent confidence intervals that ranged between 61 and 100 percent.

Samples taken June 21–30, 1962, between longs. 165°30′E and 170°30′E (Fig. 41)

North of lat. 49°30′N. All samples classified from zero to 31 percent Bristol Bay type sockeye salmon, with an average of about eight percent. The 90-percent confidence intervals included zero for all samples except one, for which the range was 7–55 percent.

Samples taken June 21–30, 1962, between longs. 170°30′E and 175°30′E (Fig. 41)

The fish in the four samples were classified 0, 0, 17, and 28 percent Bristol Bay type sockeye. The 90-percent confidence intervals included zero in three samples and ranged from 3 to 52 percent in one sample of 33 sockeye.

Samples taken July 1–20, 1962 (Fig. 42)

All samples were taken near 165°E long. The sampling dates and the small percentages of the samples classified as Bristol Bay type sockeye salmon make it unlikely that these fish were of Bristol Bay origin.

CLASSIFICATION PROCEDURE FOR IMMATURE SOCKEYE SALMON

Discriminant function analysis used in scale studies requires *a priori* knowledge of the population to be classified to continent of origin. Whereas studies (Fukuhara *et al.*, 1962) show that mature sockeye salmon in the Bering Sea and west of 165°W long. are of Kamchatkan or Bristol Bay origin, evidence is not available on the origin of immature sockeye found in this area.

Japanese tagging of both mature and immature sockeye salmon showed that Asian sockeye were found in a large area southeast of the Kamchatka Peninsula and the Kuril Islands (Hartt, MS 1964). Margolis (1963), using the nematode *Dacnitis* as an indicator, found immature Kamchatkan sockeye salmon from the east coast of Kamchatka eastward to near long. 170°W.

Margolis (1963) found immature Bristol Bay sockeye salmon from longs. 145°W to 175°E in the North Pacific Ocean and from longs. 175°W to 170°E in the Bering Sea. Hartt (MS 1964) found that immature sockeye salmon moved westward along the south side of the Aleutian Islands from late June into mid-September (when sampling was discontinued). Both the abundance and the age composition of these immature fish have been related to the run to Bristol Bay the following year.

Hartt (MS 1964), in his studies of tagging of immature sockeye salmon in the Aleutian Island area, noted that returns were essentially from the high seas and from western Alaska.

The results of these studies are believed sufficient to justify the assumption that most of the immature sockeye salmon in the Bering Sea and west of long. 165°W in the Pacific Ocean are of Kamchatkan or Bristol Bay origin. If sockeye from Gulf of Alaska rivers were present in samples taken west of long. 165°W, they would probably be classified as Kamchatkan type (Anas and Murai, MS 1964). This would introduce a bias that would increase the classification estimates of the percentage of Kamchatkan type sockeye in the samples.

Anas and Murai (MS 1964) used a linear discriminant function and a weighting method developed by Fukuhara *et al.* (1962) for samples with pooled ages and brood years that resulted in an estimate of percentage of mature Bristol Bay sockeye in high seas samples. A linear discriminant function for pooled ages and brood years was also used for immature sockeye salmon. No satisfactory method of weighting the various age classes of immature sockeye salmon for their relative abundance has been developed. The data for immature fish are therefore unweighted, as are the data for mature Asian fish.

The three scale characters used to classify sockeye salmon are formed on the scale during the first year of ocean growth. The growth patterns recorded on the scale in this year of ocean life remain, regardless of the age at which maturity occurs. This should result in similar misclassification percentages of sockeye from a single brood year and of the same freshwater age that return in successive years. For example, the average misclassification of age 4_2 Bristol Bay sockeye in 1963 was 17.0 percent and the average for age 5_2 sockeye in 1964 was 12.4 percent. The average misclassification was 8.6 percent for age 5_3 in 1963, and 1.6 percent for age 6_3 in 1964. Other age classes were either absent or not present in sufficient numbers for evaluation.

The 1962 samples collected on the high seas included immature sockeye salmon of the following ages: 3_2 (7.9%), 4_2 (25.7%), 4_3 (10.7%), 5_2 (4.6%), 5_3 (35.7%), 6_2 (0.1%), 6_3 (3.0%), 6_4 (8.8%), 7_4 (0.2%), other ages (3.3%).

The most important year classes represented were those from the 1956, 1957, 1958, and 1959 brood years. Sockeye salmon from these brood years returned to Bristol Bay as mature fish in important numbers in the spawning seasons 1960 through 1964. To estimate the percentage of Bristol Bay immature sockeye salmon misclassified to origin, the average percentage of mature fish misclassified in 1960–1964 (19.97 percent) was applied to the immature fish. Similarly, the average percentage (28.62 percent) of Kamchatkan type sockeye misclassified was computed from samples selected for 1960–63. (Data for the Asian standards for 1964 were not available.)

Results of Classifying High Seas Samples of Immature Sockeye

Samples collected on the high seas in 1962 having more than 17 immature sockeye salmon were classified to origin (Table 18). These samples were grouped by five degrees of longitude for June 6–29, 1962, and July 1-August 22, 1962, and the average corrected percentage of Bristol Bay sockeye was computed (Table 19).

The percentages of the samples classified as Bristol Bay immature sockeye increased substantially after July 1 (Table 19). In the area bounded by long. 175°W and 175°E, two samples had 74.0 and 48.0 percent Bristol Bay type fish before July 1, compared with 90.0 and 65.3 percent in two samples after July 1. High percentages (78.0, 66.0, 90.0, 65.3) of the samples collected in the area from longs. 165°W to 175°E after July 1 were classified as Bristol Bay type. The percentage of Bristol Bay immature sockeye salmon declined progressively from east to west in samples taken west of long. 175°W during June 6–29 and July 1-August 22. No Bristol Bay immature sockeye were found in the single sample from the Gulf of Alaska.

SUMMARY AND CONCLUSIONS

Mature and immature sockeye salmon collected on the high seas in 1962, and mature sockeye from inshore areas in 1962 and 1964, were classified to continent of origin by using scale characters and a linear discriminant function computed from 1957 data. Eighty-one samples with more than 29 mature sockeye caught on the high seas, and 36 samples with more than 17 immature sockeye, were available for classification.

The samples collected closest to the Aleutian Islands after June 1 generally had higher percentages of mature Bristol Bay sockeye salmon than those collected farther offshore.

From June 1–10, samples averaged about 88 percent Bristol Bay type sockeye salmon in the area

TABLE 18. Classification of samples of immature sockeye salmon collected in 1962 by Japanese motherships and United States research vessels.

Sample number	Sampling date	Sampling location		Sample size	Number of Bristol Bay sockeye	Percent classified		Corrected percent Bristol Bay type	90% confidence interval[1]
		Lat. (N)	Long.			Bristol Bay type	Kamchatkan type		
1	6/6	49—47	176—12 E	26	16	61.53	38.47	64	34—94
2	6/6	49—33	176—45 E	18	8	44.44	55.56	32	0—68
3	6/11	50—57	176—00W	18	12	66.66	33.34	74	38—100
4	6/12	47—14	169—56 E	33	8	24.24	75.76	0	0—25
5	6/12	47—42	168—15 E	22	8	36.36	63.64	15	0—48
6	6/25	51—10	170—41 E	26	17	65.38	34.62	72	42—100
7	6/26	50—58	170—05 E	21	14	66.66	33.34	74	41—100
8	6/27	51—02	171—01 E	18	7	38.89	61.11	20	0—57
9	6/28	50—53	171—11 E	38	16	42.10	57.90	26	1—52
10	6/29	50—20	168—28 E	21	8	38.09	61.91	18	0—52
11	7/1	50—33	165—39 E	18	5	27.77	72.23	0	0—34
12	7/2	51—00	177—00W	92	69	75.00	25.00	90	76—100
13	7/3	50—10	166—34 E	27	13	48.14	51.86	38	7—69
14	7/5	50—33	165—41 E	23	7	30.43	69.57	4	0—34
15	7/5	50—42	165—59 E	24	5	20.83	79.17	0	0—30
16	7/7	50—04	162—43 E	21	7	33.33	66.67	9	0—42
17	7/7	50—16	164—54 E	30	10	33.33	66.67	9	0—37
18	7/11	50—20	163—32 E	21	7	33.33	66.67	9	0—42
19	7/12	52—52	167—07W	275	219	79.63	20.37	99	91—100
20	7/13	50—20	163—32 E	28	6	21.42	78.58	0	0—27
21	7/13	50—56	163—10 E	21	4	19.04	80.96	0	0—32
22	7/14	51—50	167—00W	212	138	65.09	34.91	71	60—81
23	7/15	52—20	166—58W	57	35	61.40	38.60	64	43—84
24	7/15	49—46	164—52 E	30	10	33.33	66.67	9	0—37
25	7/15	59—14	165—13 E	31	14	45.16	54.84	32	4—61
26	7/17	51—00	170—52W	57	38	66.66	33.34	74	54—94
27	7/18	51—28	170—58W	157	88	56.05	43.95	53	41—66
28	7/21	50—37	169—32 E	44	13	29.54	70.46	2	0—24
29	7/21	50—37	169—21 E	43	18	41.86	58.14	26	2—50
30	7/23	51—27	168—56 E	41	15	36.58	63.42	16	0—40
31	7/23	51—39	169—06 E	40	15	37.50	62.50	17	0—42
32	7/25	51—33	174—04W	92	60	65.21	34.79	71	55—87
33	8/4	50—50	179—00 E	34	20	58.82	41.18	59	32—86
34	8/8	50—19	178—59 E	137	76	58.47	41.53	58	45—72
35	8/9	51—12	176—00 E	268	186	69.40	30.60	79	70—88
36	8/22	51—45	154—00W	75	11	14.66	85.34	0	0—17

[1] Truncated at 0 percent and 100 percent.

between 179°30′W long. to 174°30′W long., compared with about 67 percent, 66 percent, and 4 percent in areas 175°30′E to 179°30′W, 170°30′E to 175°30′E, and 165°30′E to 170°30′E long., respectively. After June 10, most of the available samples (from west of long. 171°30′E) were classified as having small percentages of Bristol Bay sockeye. The three samples collected near 175°W long. in the period June 11–20 had high percentages (80, 87, 100) of Bristol Bay sockeye.

The percentages of immature Bristol Bay sockeye salmon in the samples collected from June 6–29, 1962, were: 74.0 for the area from 175°W long. to 180°, 48.0 for the area from 180° to 175°E long., 48.0 for the area from 175°E to 170°E long., and 11.0 for the area from 170°E to 165°E long., showing a decline to the west. In comparison, percentages of immature Bristol Bay sockeye were higher in samples collected after July 1, as follows: 78.0 for the area from 165°W to 170°W long., 66.0 for the area from 170°W to 175°W long., 90.0 for the area from 175°W to 180°, 65.3 for the area from 180° to 175°E long., 15.0 for the area from 170°E to 165°E long., and 6.0 for the area from 165°E to 160°E long. No Bristol Bay immature sockeye were found in the single sample from the Gulf of Alaska collected on August 22.

Table 19. Classification of high seas samples of immature sockeye salmon, grouped by 5° of longitude, June 6–29, 1962, and July 1–August 22, 1962.

Date and longitude	Sample size	Number of Bristol Bay sockeye	Average corrected percent Bristol Bay sockeye	Percentage range
6/6—6/29				
165 E—170 E	76	24	11.0	0—18
170 E—175 E	103	54	48.0	20—74
175 E—180	44	24	48.0	32—64
180 —175W	18	12	74.0	74—74
7/1—8/22				
160 E—165 E	151	44	6.0	0—9
165 E—170 E	291	105	15.0	0—38
175 E—180	439	282	65.3	58—79
180 —175W	92	69	90.0	90—90
175W—170W	306	186	66.0	53—74
170W—165W	544	392	78.0	61—99
155W—150W	75	11	0	0—0

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PINK SALMON SCALE STUDIES

by Roger E. Pearson

The primary objective of the scale studies was to classify pink salmon collected on the high seas to continent of origin. Methods of collecting, processing, and analyzing data for this purpose were presented by Pearson (1964a, 1964b, and 1966) for 1959 and 1963. This report summarizes the results of studies completed in 1965.

Included here are (1) arithmetic means and standard deviations of scale characters obtained from the 1964 collections in North America, (2) comparisons of scale character mean values between North American samples collected in 1963 and 1964, (3) comparisons of scale character mean values between samples taken from the eastern North Pacific Ocean in 1963 and from North American spawning regions in 1963, (4) arithmetic means and standard deviations of scale characters obtained from Kodiak Island pink salmon from 1957 through 1964, and (5) tests to determine if the measurements taken from scales of Bella Bella pink salmon on three different dates in 1963 were the same.

Arithmetic Means and Standard Deviations of Scale Characters Obtained From the 1964 Collections in North America

Fourteen different scale measurements were obtained from the 1964 North American scale samples

TABLE 20. List of pink salmon scale characters[1].

Scale character number	Character
14	Width from center of focus to 5th circulus.
15	Width from center of focus to 10th circulus.
16	Width from center of focus to 15th circulus.
17	Width from center of focus to 20th circulus.
18	Width from center of focus to 25th circulus.
19	Width from center of focus to 30th circulus.
20	Width from 5th to 10th circulus.
21	Width from 10th to 15th circulus.
22	Width from 15th to 20th circulus.
23	Width from 20th to 25th circulus.
24	Width from 25th to 30th circulus.
25	Width from 15th to 30th circulus.
26	Width from 10th to 20th circulus.
27	Width from 20th to 30th circulus.

[1] All scales were examined at 100× magnification. Each measurement was to the nearest millimeter. All scale character numbers are the same as used by Pearson (1966).

for use as racial characters (Table 20). These are the same characters that were taken from the 1963 collections and include the characters that were best for differentiating fish from North American spawning regions in 1959 (Pearson, 1966).

Arithmetic means and standard deviations for the 14 scale characters are shown in Table 21 for 1964. The ranges in mean value varied widely for all characters. Smaller means frequently occurred in samples taken from British Columbia and part of southeastern Alaska (characters 16–27). Larger mean values occurred with some characters in samples taken in Cook Inlet, Kodiak Island, the Alaska Peninsula, and Bristol Bay (characters 19, 21, and 24–27). The means of some characters became progressively larger with an increase in latitude of the spawning region (characters 17–20, 23–25, and 27).

COMPARISONS OF MEAN VALUES OF SCALE CHARACTERS, PINK SALMON COLLECTED IN NORTH AMERICA IN 1963 AND 1964

The mean values of scale characters in samples obtained in 1964 from North American spawning regions were compared with the means of the 1963 samples from North America. The mean values for 1964 are listed in Table 21 ; the mean values for 1963 are from Pearson (1966). In the British Columbia samples, the mean values of scale characters 14–23 and 25–27 were smaller in 1964. The mean values of most scale characters in Alaskan samples were also smaller in 1964. The characters follow a pattern similar to the relationship shown in Figure 43 for character 19. Here, every region had smaller mean values in 1964. Figure 44 shows that this relationship did not occur with character 24, for some regions had either similar values in both years, or larger values in 1964.

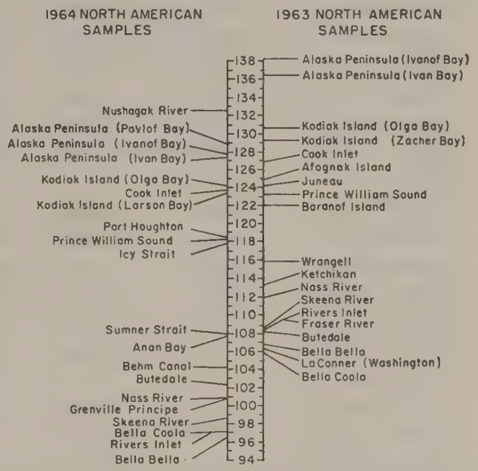

FIGURE 43. Linear comparison of mean values of scale character 19 (width from center of focus to 30th circulus) for North American samples collected in 1963 and 1964.

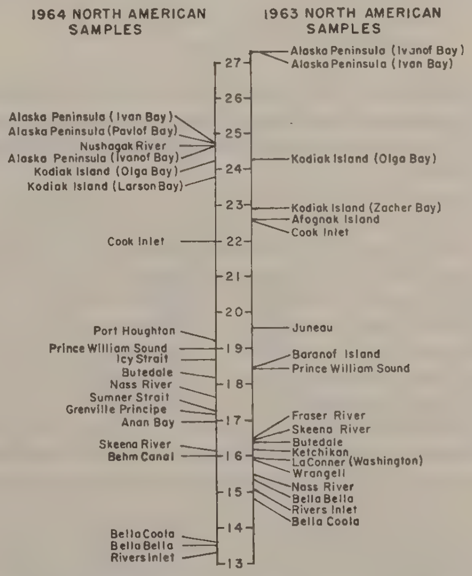

FIGURE 44. Linear comparison of mean values of scale character 24 (width from 25th to 30th circulus) for North American samples collected in 1963 and 1964.

TABLE 21. Arithmetic means and (in parentheses) standard deviations of measurements

Area	Date	Sample size	14	15	16	17	18
BRITISH COLUMBIA							
Rivers Inlet	8/4	68	24.6(2.3)	39.7(3.5)	56.2(4.7)	71.8(5.6)	83.8(6.9)
Bella Coola	7/22, 23	215	23.0(2.3)	38.1(3.4)	55.2(4.8)	71.0(6.0)	83.5(6.5)
Bella Bella	7/22, 23, 27, 28	296	23.3(2.5)	38.6(3.6)	55.5(5.1)	71.1(6.2)	83.1(7.0)
Butedale	8/18, 20	211	25.2(2.5)	41.4(3.5)	58.1(4.7)	71.7(6.0)	84.1(6.7)
Grenville	8/4, 5, 6	246	24.6(2.7)	40.7(3.9)	57.6(5.3)	71.3(6.0)	83.6(6.8)
Skeena River	8/2, 3, 4, 5	274	23.9(2.6)	39.3(3.7)	56.1(4.8)	70.5(5.5)	82.6(5.9)
Nass River	8/3, 4, 5; 7/31	215	24.8(2.8)	40.6(3.8)	56.7(4.8)	70.9(6.2)	83.3(7.1)
ALASKA							
Southeastern:							
Behm Canal	7/22	238	24.8(2.3)	41.8(3.3)	58.4(4.6)	74.7(6.5)	88.2(7.7)
Anan Bay	7/20	97	26.3(2.7)	43.1(3.5)	60.4(4.3)	76.5(5.7)	90.7(6.5)
Sumner Strait	8/25	77	25.6(3.1)	42.0(4.2)	59.2(5.4)	75.9(6.7)	90.6(7.8)
Port Houghton	7/20	262	26.4(2.4)	46.2(3.6)	65.1(4.8)	84.1(5.9)	99.3(6.7)
Icy Strait	7/15	248	26.9(2.7)	46.0(3.8)	64.7(5.1)	84.0(6.5)	99.3(7.4)
Prince William Sd.	8/3, 4	233	25.1(2.5)	43.6(3.8)	63.4(5.2)	83.3(6.1)	99.3(6.7)
Cook Inlet	7/25	318	23.2(2.5)	42.5(4.0)	65.2(5.4)	85.8(6.2)	101.8(7.1)
Kodiak Island:							
Larson Bay	8/12	236	25.1(2.3)	44.1(3.6)	65.1(4.9)	83.8(6.0)	99.8(6.6)
Olga Bay	8/5	235	22.8(2.1)	40.4(3.9)	62.8(5.5)	83.3(6.4)	100.1(7.1)
Alaska Peninsula:							
Pavlof Bay	7/24	306	22.8(2.3)	42.8(4.1)	67.2(5.4)	85.5(6.3)	104.3(7.5)
Ivan Bay	7/27	313	23.1(2.5)	42.1(4.4)	65.3(5.6)	83.8(6.4)	102.7(7.7)
Ivanof Bay	7/28	330	23.9(2.5)	44.1(4.0)	67.1(5.3)	84.6(6.2)	103.2(7.6)
Ivan-Ivanof Bay[2]	7/18	316	24.0(2.5)	44.1(4.2)	67.0(5.3)	84.8(6.1)	103.4(7.3)
Bristol Bay:							
Nushagak River	7/27, 28, 29	357	22.2(2.2)	40.4(3.7)	64.2(5.9)	85.9(6.6)	105.8(8.0)

[1] The character description is found in Table 20.

[2] Mixed fish sampled at a cannery.

COMPARISONS OF MEAN VALUES OF SCALE CHARACTERS FROM PINK SALMON COLLECTED ON THE HIGH SEAS AND FROM NORTH AMERICAN SPAWNING REGIONS IN 1963

Mean values of scale character 19 (width from center of focus to 30th circulus) were obtained from all 1963 high seas samples with 100 or more pink salmon. The means and standard deviations of these samples are shown in Table 22. Comparison of these data with the North American inshore values presented by Pearson (1965) shows that the standard deviations of the high seas samples were only slightly larger than the standard deviations of the inshore samples. The low standard deviations show that few fish with different scale measurements were present in the high seas samples[3]; this suggests that most of the fish in

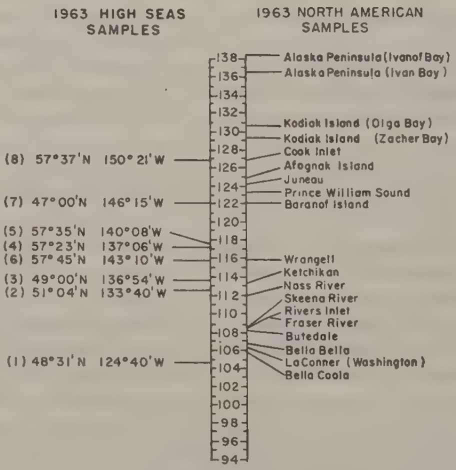

FIGURE 45. Linear comparison of mean values of scale character 19 (width from center of focus to 30th circulus) for 1963 high seas samples and 1963 North American spawning region samples.

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[3] If fish from regions that have different mean values are mixed, the standard deviation of character 19 will be larger than those in the individual regional samples. For example, the standard deviation for a mixed sample of Olga Bay (205 fish) and Bella Coola (263 fish) scales was 15.0. The regional standard deviations were 9.4 for Olga Bay and 7.9 for Bella Coola.

(millimeters) of scale characters from the 1964 North American samples of pink salmon.

Character number[1]								
19	20	21	22	23	24	25	26	27
97.1(7.6)	15.1(2.4)	16.5(2.3)	15.6(2.2)	12.0(2.8)	13.3(3.0)	40.9(4.7)	32.1(3.4)	25.3(3.6)
97.1(7.2)	15.1(2.1)	17.1(2.4)	15.9(2.2)	12.5(2.1)	13.6(3.1)	41.9(4.2)	33.0(3.7)	26.1(3.7)
96.6(7.8)	15.3(2.1)	17.0(2.4)	15.6(2.4)	11.9(2.0)	13.5(3.1)	41.0(4.3)	32.5(3.9)	25.5(3.4)
102.3(8.2)	16.2(2.1)	16.7(2.4)	13.6(2.5)	12.4(2.3)	18.2(4.4)	44.3(5.6)	30.3(4.0)	30.6(5.6)
100.8(8.5)	16.1(2.3)	16.9(2.8)	13.7(2.4)	12.3(2.5)	17.2(3.9)	43.2(5.2)	30.6(3.9)	29.5(5.1)
98.7(7.3)	15.4(2.2)	16.8(2.7)	14.3(2.2)	12.1(2.1)	16.1(3.5)	42.5(4.5)	31.2(3.7)	28.2(4.3)
100.9(8.4)	15.8(2.0)	16.1(2.4)	14.2(2.7)	12.3(2.4)	17.7(4.0)	44.2(5.1)	30.4(3.9)	30.0(5.0)
104.1(8.2)	17.0(2.1)	16.6(2.2)	16.2(2.9)	13.5(2.7)	16.0(3.6)	45.7(5.2)	32.9(4.3)	29.5(4.4)
107.7(7.4)	16.9(1.9)	17.3(2.2)	16.1(2.8)	14.2(2.6)	16.9(3.7)	47.3(4.7)	33.4(4.0)	31.1(4.5)
107.9(8.7)	16.4(2.1)	17.2(2.3)	16.7(2.9)	14.8(2.7)	17.2(3.4)	48.7(5.3)	33.9(4.1)	32.0(4.1)
118.5(8.3)	19.8(2.2)	18.9(2.4)	19.0(2.6)	15.2(2.2)	19.2(3.4)	53.4(5.0)	37.8(3.7)	34.4(4.1)
117.9(8.7)	19.1(2.1)	18.7(2.2)	19.2(2.6)	15.3(2.1)	18.7(3.5)	53.2(5.0)	38.0(4.0)	34.0(3.8)
118.2(7.8)	18.5(2.2)	19.7(2.4)	20.0(2.5)	15.9(2.2)	19.0(3.4)	54.9(5.1)	39.7(3.7)	34.9(4.0)
123.9(8.7)	19.4(2.3)	22.7(2.5)	20.6(2.6)	16.0(2.0)	22.0(3.4)	58.6(5.3)	43.3(3.9)	38.1(4.4)
123.5(8.5)	18.9(2.2)	21.0(2.4)	18.8(2.4)	15.9(2.4)	23.7(3.4)	58.4(5.4)	39.7(3.8)	39.6(4.7)
124.3(8.8)	17.5(3.2)	22.5(2.7)	20.4(2.7)	16.8(2.2)	24.2(3.2)	61.4(5.5)	42.9(4.1)	41.0(4.3)
128.9(9.4)	20.0(2.7)	24.4(2.6)	18.3(2.4)	18.7(3.2)	24.7(3.2)	61.8(5.7)	42.7(4.1)	43.4(5.1)
127.5(9.4)	19.0(2.8)	23.2(2.5)	18.5(2.5)	18.9(2.9)	24.8(3.0)	62.2(5.4)	41.7(3.8)	43.7(4.6)
127.8(9.5)	20.3(2.3)	22.9(2.5)	17.5(2.2)	18.6(3.1)	24.6(3.0)	60.7(5.7)	40.5(3.7)	43.2(4.9)
127.8(9.2)	20.1(2.4)	22.9(2.6)	17.8(2.2)	18.6(3.2)	24.5(3.2)	60.8(5.6)	40.7(4.0)	43.0(5.0)
132.5(9.9)	18.2(2.3)	23.8(3.1)	21.7(2.6)	19.9(2.7)	26.6(3.1)	68.2(5.7)	45.5(4.0)	46.5(4.6)

TABLE 22. Arithmetic means and standard deviations of measurements (millimeters) of scale character 19 (width from center of focus to 30th circulus) from 1963 high seas samples.

Sample number	Location		Date	Sample[1] size	Mean	*s*
	Lat. (N)	Long. (W)				
1	48—31	124—40	8/18	101	104.5	6.6
2	51—04	133—40	6/2	94	112.3	10.0
3	49—00	136—54	5/27	90	113.5	10.9
4	57—23	137—06	6/14	146	117.2	10.7
5	57—35	140—08	7/1	95	117.7	9.7
6	57—45	143—10	6/30	112	115.7	11.1
7	47—00	146—15	5/19	63	122.0	10.5
8	57—37	150—21	7/12	84	126.8	10.3

[1] Samples with 100 or more fish were originally examined; however, some scales could not be used because they were regenerated or had a dirty surface.

Table 23. Arithmetic means and (in parentheses) standard deviations of measurements (millimeters)

Area[1/2]	Date	Sample size	14	15	16	17	18
Uyak Bay	7/30/57	72	26.9(3.0)	47.3(4.7)	73.0(6.3)	92.4(6.5)	110.2(7.8)
Larson Bay	7/26/58	89	26.5(2.6)	46.3(3.8)	67.2(4.4)	87.1(5.1)	101.7(6.1)
Karluk Lagoon	7/30/58	87	25.4(2.1)	46.1(3.1)	67.9(4.4)	88.2(5.5)	103.9(6.5)
Uyak Bay	8/6/59	56	27.8(2.8)	46.0(4.5)	67.5(5.9)	86.8(7.3)	102.2(7.9)
Karluk Lagoon	7/28/60	106	25.9(2.7)	46.1(4.3)	68.7(5.4)	87.6(5.9)	103.6(6.8)
Uyak Bay	8/11/61	84	27.8(2.8)	47.8(4.7)	69.9(6.3)	90.3(7.6)	106.5(8.4)
Olga Bay	8/11/61	57	26.2(2.8)	44.5(4.6)	67.7(6.1)	88.6(7.2)	104.8(8.7)
Karluk Lagoon	7/25/62	71	26.7(2.8)	45.2(4.0)	65.1(5.1)	85.6(6.2)	100.8(7.1)
Olga Bay	7/22/63	205	24.7(2.2)	45.2(3.9)	69.3(5.4)	90.0(6.5)	106.3(7.4)
Uyak Bay	8/7/63	163	29.1(2.9)	49.6(4.1)	71.3(5.2)	91.5(5.9)	106.4(7.0)
Olga Bay	8/5/64	235	22.8(2.1)	40.4(3.9)	62.8(5.5)	83.3(6.4)	100.1(7.1)
Larson Bay	8/12/64	236	25.1(2.3)	44.1(3.6)	65.1(4.9)	83.8(6.0)	99.8(6.6)

[1] Ninety-five fish were sampled at Karluk River weir August 22, 1956, but all their " preferred " scales were eroded.

[2] Scale samples were collected from 76 fish at Olga Bay on August 9, 1959, but most of the scales (69) were eroded too extensively for use ; the sample was discarded.

[3] The character description is found in Table 20.

each sample were from one region or they were from regions with similar scale measurements.

Figure 45 shows that the mean value of high seas sample number 1 was most similar to mean values for Washington and British Columbia ; mean values of samples 2 through 6 were close to those of northern British Columbia and part of southeastern Alaska ; sample 7 was like Baranof Island and Prince William Sound ; and sample number 8 was similar to Afognak Island, Cook Inlet, and Kodiak Island.

The scale data from the high seas samples were examined to determine if East Kamchatkan stocks were present, for pink salmon tagged in Alaskan coastal waters were recovered in East Kamchatka in 1963 (Hartt and Dell, 1964). Since Asian scale samples were not obtained in 1963, the mean value of scale character 19 was not known for the East Kamchatkan stocks. In 1959, however, East Kamchatkan mean values were 136.5 and 139.2 (Pearson, 1966). These values were much larger than the means of the high seas samples listed in Table 22. Assuming that the 1963 East Kamchatka scales were similar to 1959, the small mean values in Table 22 indicate that very few East Kamchatkan pink salmon could be present in the eight high seas samples.

Arithmetic Means and Standard Deviations of Scale Characters From Kodiak Island Pink Salmon in 1957–64

The objective of this study was to determine if scale character mean values (characters 14–27) from one region varied between years. Kodiak Island samples were selected. More scale samples were collected from this area in 1957–64 than from other North American spawning regions.

Table 23 lists the means and standard deviations of scale characters from the Kodiak Island samples. The ranges in mean value showed some variation between years. Figures 46 and 47 show that the mean values of character 19 for Kodiak Island were large in both odd- and even-numbered years. This relationship held for all characters in odd-numbered years, but some characters had smaller mean values in even-numbered years (Figures 48 and 49). The sampling sites within Kodiak Island were different in

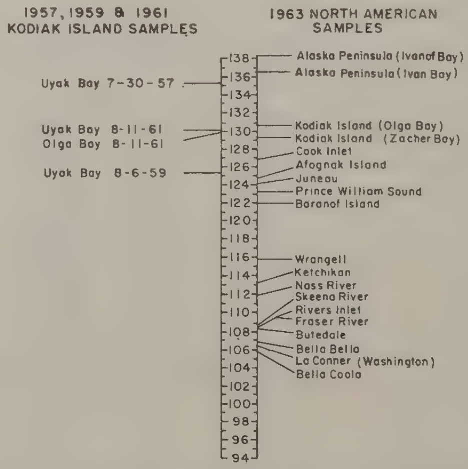

Figure 46. Linear comparison of mean values of scale character 19 (width from center of focus to 30th circulus) for North American samples collected in 1963 and Kodiak Island samples collected in other odd-numbered years.

of scale characters from Kodiak Island pink salmon scales collected in 1957-64.

Character number[3]								
19	20	21	22	23	24	25	26	27
135.3(9.7)	20.4(2.6)	25.7(2.9)	19.5(3.1)	17.7(2.8)	25.1(3.4)	62.3(5.5)	45.1(3.9)	42.8(5.1)
120.4(7.0)	19.8(2.2)	20.9(1.9)	19.9(2.5)	14.6(2.2)	18.6(3.3)	53.2(4.6)	40.8(3.5)	33.2(3.6)
123.6(8.8)	20.8(2.2)	21.7(2.6)	20.3(2.5)	15.7(2.8)	19.6(4.0)	55.7(5.9)	42.1(4.1)	35.4(5.0)
125.4(9.0)	18.2(2.6)	21.5(2.7)	19.2(2.7)	15.4(1.6)	23.1(3.6)	57.8(5.1)	40.8(4.2)	38.6(3.9)
126.0(8.4)	20.1(2.5)	22.6(2.6)	18.9(2.2)	16.0(2.2)	22.4(3.8)	57.3(5.2)	41.5(3.7)	38.4(4.7)
130.1(9.9)	19.9(3.0)	22.2(2.8)	20.4(3.0)	16.2(2.3)	23.6(3.8)	60.2(5.9)	42.6(4.6)	39.8(4.9)
129.7(10.9)	18.3(2.8)	23.2(2.6)	20.9(2.6)	16.2(2.7)	24.9(3.8)	62.0(6.6)	44.1(4.1)	41.1(5.5)
123.8(8.5)	18.6(2.1)	19.8(2.5)	20.6(2.6)	15.2(1.9)	23.0(3.2)	58.8(5.2)	40.4(3.5)	38.2(4.0)
130.5(9.4)	20.6(2.8)	24.1(2.8)	20.6(3.1)	16.3(2.5)	24.3(3.5)	61.2(5.9)	44.7(4.6)	40.6(5.0)
129.2(9.2)	20.5(2.2)	21.7(2.4)	20.2(2.3)	14.9(2.1)	22.9(4.3)	57.9(5.8)	41.9(3.5)	37.8(5.3)
124.3(8.8)	17.5(3.2)	22.5(2.7)	20.4(2.7)	16.8(2.2)	24.2(3.2)	61.4(5.5)	42.9(4.1)	41.0(4.3)
123.5(8.5)	18.9(2.2)	21.0(2.4)	18.8(2.4)	15.9(2.4)	23.7(3.4)	58.4(5.4)	39.7(3.8)	39.6(4.7)

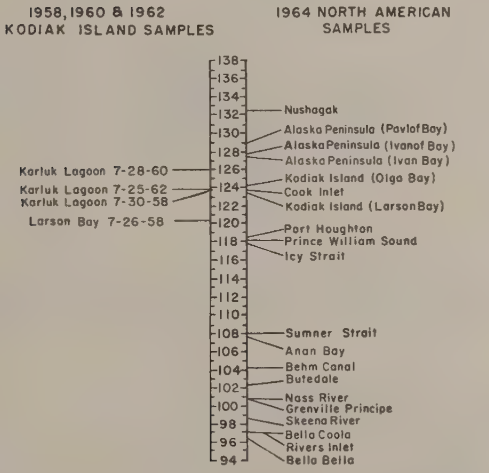

FIGURE 47. Linear comparison of mean values of scale character 19 (width from center of focus to 30th circulus) for North American samples collected in 1964 and Kodiak Island samples collected in other even-numbered years.

the even- and odd-year cycles, however, and this could account for some of the observed differences in scale measurements.

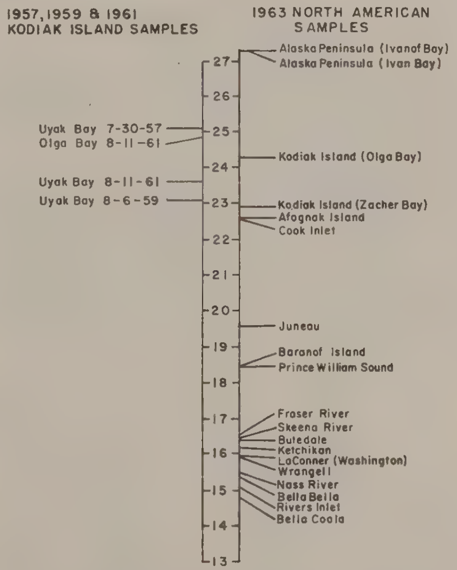

FIGURE 48. Linear comparison of mean values of scale character 24 (width from 25th to 30th circulus) for North American samples collected in 1963 and Kodiak Island samples collected in other odd-numbered years.

ARITHMETIC MEANS AND STANDARD DEVIATIONS OF SCALE CHARACTERS OBTAINED FROM BELLA BELLA PINK SALMON COLLECTED ON THREE DIFFERENT DATES IN 1963

The objective of this study was to determine if differences occurred in scale measurements (characters 14–27) between samples from one spawning region collected on different dates in a season. Differences in scale characters between dates could bias the results of studies for determining the region of origin of pink salmon caught on the high seas. Not many samples were available to adequately examine this important subject. Most pink salmon runs were of

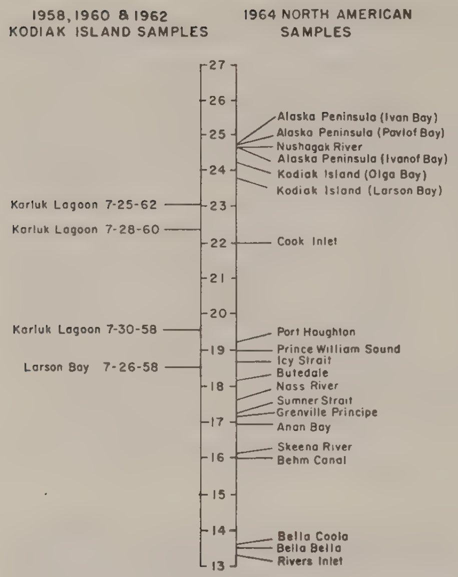

FIGURE 49. Linear comparison of mean values of scale character 24 (width from 25th to 30th circulus) for North American samples collected in 1964 and Kodiak Island samples collected in other even-numbered years.

short duration, and it was difficult to obtain large samples from one stock that were taken more than a few weeks apart. The best available samples were taken from Bella Bella over a 3-week period in 1963.

Each character was tested to determine if differences occurred in measurements between dates in the Bella Bella samples. A one-way analysis of variance test was used. Characters 17, 18, 21, and 24 were significantly different at the five percent level; and characters 22 and 26 were significantly different at the one percent level. Although some scale measurements were different between dates, all had small mean values (Table 24) compared with North American samples from part of southeastern Alaska, Afognak Island, Prince William Sound, Cook Inlet, Kodiak Island, and the Alaska Peninsula. This relationship is shown in Figures 50 and 51 for scale characters 19 and 24.

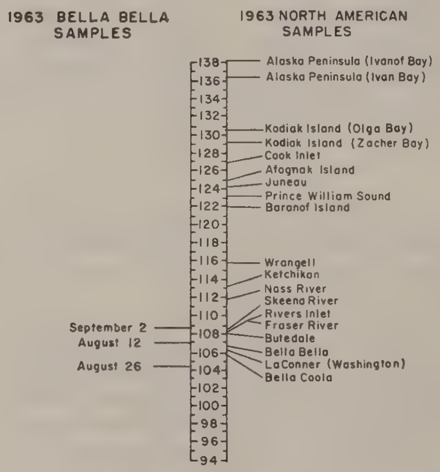

FIGURE 50. Linear comparison of mean values of scale character 19 (width from center of focus to 30th circulus) for Bella Bella samples collected on three different dates in 1963 and from 1963 samples from North American spawning regions.

TABLE 24. Arithmetic means and (in parentheses) standard deviations of scale characters from 1963 Bella Bella pink salmon collected August 12, August 26, and September 2.

Character number[1]	August 12 (39 fish)	August 26 (38 fish)	September 2 (32 fish)
14	24.8(3.2)	25.5(2.8)	26.2(2.4)
15	42.0(4.7)	41.7(4.0)	43.5(4.3)
16	61.2(5.8)	59.5(5.2)	61.7(5.0)
17	78.6(6.3)	75.4(5.7)	78.2(5.3)
18	92.7(7.6)	88.9(6.2)	92.6(6.4)
19	107.2(8.1)	104.5(7.5)	108.7(7.7)
20	17.2(2.1)	16.2(2.4)	17.2(2.8)
21	19.2(2.2)	17.8(3.0)	18.2(2.1)
22	17.5(2.2)	15.9(2.4)	16.5(2.0)
23	14.1(2.2)	13.4(2.0)	14.4(2.2)
24	14.4(2.0)	15.6(3.1)	16.1(3.1)
25	46.0(3.8)	45.0(4.4)	47.0(5.0)
26	36.7(3.3)	33.7(3.8)	34.7(2.9)
27	28.5(3.2)	29.0(4.2)	30.5(3.9)

[1] See Table 20 for description of characters.

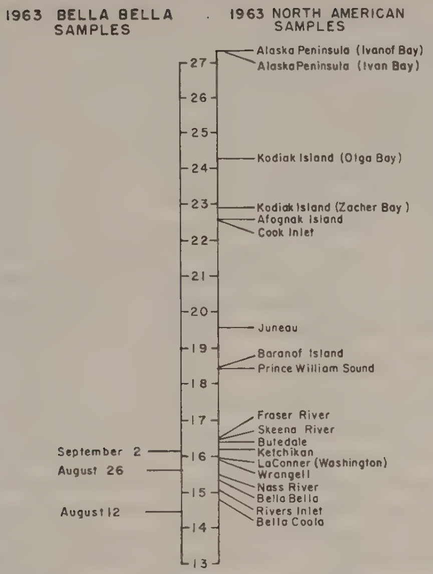

Figure 51. Linear comparison of mean values of scale character 24 (width from 25th to 30th circulus) for Bella Bella samples collected on three different dates in 1963 and 1963 values for samples from North American spawning regions.

Summary and Conclusions

Arithmetic means and standard deviations of 14 scale characters were calculated from the 1964 collections in spawning regions. No Asian scales were examined. The ranges in mean value varied widely for all characters. Many scale characters differed between samples from North American spawning regions.

The mean values of scale characters in samples obtained in 1964 from North American spawning regions were compared with the means of the 1963 samples from North America. The mean values of most scale characters were smaller in 1964. In both years, the mean values of some characters became progressively larger with an increase in latitude of the spawning region.

Scale character mean values of eight 1963 high seas samples were compared with values of 1963 samples from spawning regions. The mean values of five high seas samples were similar to mean values found in British Columbia and southeastern Alaska samples. One high seas sample had a mean like those of Baranof Island and Prince William Sound. Another sample was most similar to Washington and British Columbia. The eighth high seas sample had a mean close to that of samples from Afognak Island, Cook Inlet, and Kodiak Island. The mean values of the high seas samples were not similar to 1959 East Kamchatkan values.

Kodiak Island samples that were collected from 1957 to 1964 were examined to determine if mean values of scale characters varied from year to year. The means showed some variation between years; however, the means of all characters were large in the odd-numbered years. Some characters had smaller mean values in even-numbered years.

Bella Bella samples that were taken on three different dates in 1963 were examined for differences in scale character values between dates. Six of the 14 characters examined were different between dates. Although some characters were different, all had small mean values compared with North American samples from part of southeastern Alaska, Afognak Island, Prince William Sound, Cook Inlet, Kodiak Island, and the Alaska Peninsula.

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POPULATION DYNAMICS

by R. A. Fredin, G. Hirschhorn, and S. Murai

In 1965, biometric research on the dynamics of exploited fish populations of the North Pacific Ocean included studies of the scientific aspects of the rationality of high seas salmon fishing; fishing mortality, natural mortality, and growth rates of king crab in the eastern Bering Sea; and fluctuations in catches and relative abundance of salmon on the high seas as indicated by salmon fishery statistics from Japanese motherships. These studies are reviewed in the following three sections.

Scientific Aspects of the Rationality of High Seas Salmon Fishing

Three papers having a direct bearing on the rationality of high seas salmon fishing have been published:

(1) Fredin, R. A. 1964. Ocean mortality and maturity schedules of Karluk River sockeye salmon and some comparisons of marine growth and mortality rates. *U.S. Fish and Wildl. Serv., Fish. Bull.*, 63 (3): 551–574.

(2) Fredin, R. A. 1965. Some methods for estimating ocean mortality of Pacific salmon and applications. *J. Fish. Res. Bd. Can.*, 22 (1): 33–51.

(3) Hirschhorn, George. 1966. Effect of growth pattern and exploitation features on yields of pink salmon in the northwestern North Pacific. *Trans. Amer. Fish. Soc.*, 95 (1): 39–51.

The first paper shows that, except for the relatively scarce 4-winter-at-sea fish under one of four different temporal distributions of oceanic natural mortality considered, any capture of Karluk sockeye salmon before the end of their ocean life causes a loss of potential yield, provided an inshore fishery exists capable of catching the fish not needed for reproduction. The second paper gives estimates of natural mortality during the last or penultimate years of ocean life of sockeye from Bristol Bay and Karluk River. The estimates of average monthly instantaneous mortality rates are lower than corresponding estimates of growth rates available for either Bristol Bay sockeye (Lander and Tanonaka, 1964) or Karluk sockeye (Ricker, 1962). The third paper deals with the effects of different growth patterns and exploitation features on yields of pink salmon in the northwestern Pacific Ocean.

Fishing Mortality, Natural Mortality, and Growth Rates of King Crab in the Eastern Bering Sea

An analysis of tag recoveries from a part of the U.S. king crab tagging program in eastern Bering Sea (1955–60 releases) was completed (Hirschhorn, 1965).

Parameter estimates were obtained for natural mortality, catchability coefficient (for Japanese tanglenet gear, in use from 1956–61), and growth in carapace length. The results suggest that the instantaneous rate of natural mortality of the king crab increases with size (age) throughout most of the fishable lifespan. Catchability coefficients were also found to be strongly related to carapace length, confirming earlier results by Miyahara and Shippen (1965) which were based on estimates of total abundance (by 5 mm group) and length-frequencies in samples of the commercial catches of Japanese factoryships in 1957 and 1958.

The distribution of biomass in a cohort of freshly recruited king crabs was estimated by means of the parameter estimates of mortality and observed growth increments by time at liberty. The distribution indicated that animals of about 160 mm carapace length are likely to constitute the optimal size group in terms of potential yield. This size group was the dominant modal group in earlier years but modal values of Japanese-caught animals have shifted gradually from 170 mm in 1955 to 150 mm in 1965. The achievement of existing quotas has become progressively more dependent on the catches of relatively small animals.

The relative abundance of the optimal size group in catches of king crabs in the eastern Bering Sea may have decreased (in 1965) by as much as two-thirds from the level of 1955–60. However, factors affecting presently available indices of relative abundance cannot now be examined in greater detail for lack of suitable data.

Analysis of Salmon Fishery Statistics from Japanese Motherships

Fishery statistics for the Japanese mothership salmon fishery for 1964 (INPFC 1964 Statistical Yearbook) were combined with corresponding data for 1952–63 (Manzer *et al.*, 1965; and INPFC 1961–1963 Statistical Yearbooks) for an analysis of annual and intraseasonal fluctuation in catches and catch per unit of effort of sockeye, pink, chum, coho, and chinook salmon in the North Pacific Ocean and Bering Sea west of long. 175°W.

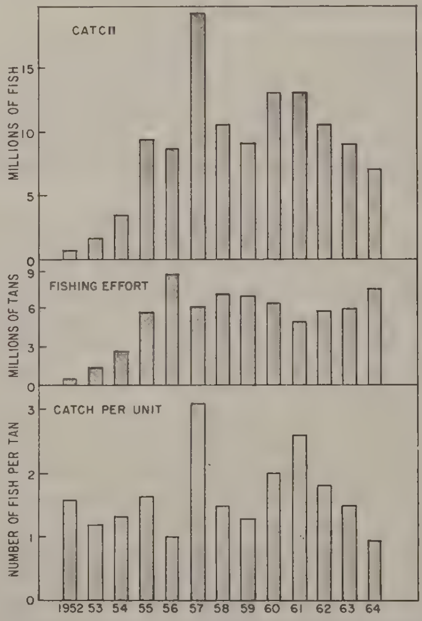

Figure 52. Sockeye salmon catch, fishing effort, and catch per unit effort, Japanese mothership salmon fishery, longs. 160°E to 175°W, 1952–64 (entire season).

TABLE 25. Salmon fishery statistics from Japanese motherships, 160°E longitude to 175°W longitude, 1952–64[1].

Year	Species					All species
	Sockeye	Pink	Chum	Coho	Chinook	
			Catch (thousands of fish)			
1952	738	698	629	24	1	2,091
1953	1,534	2,892	2,678	307	3	7,414
1954	3,382	2,698	8,254	675	57	15,071
1955	9,456	9,108	14,012	1,467	43	34,164
1956	8,702	6,589	15,316	3,393	117	34,170
1957	19,403	17,204	8,877	193	25	46,042
1958	10,708	7,859	14,048	3,106	38	35,832
1959	9,125	18,642	12,856	1,388	63	42,326
1960	12,879	1,826	10,517	862	180	26,324
1961	12,998	3,226	6,128	281	31	22,704
1962	10,590	1,011	6,372	1,531	122	19,755
1963	8,902	6,242	5,858	1,890	88	23,475
1964	7,097	2,198	8,640	3,533	410	21,964
			Fishing effort (thousands of tans)			
1952	471	394	471	199	471	471
1953	1,314	1,027	1,314	619	1,314	1,314
1954	2,547	2,265	2,547	1,253	2,547	2,547
1955	5,761	4,511	5,761	2,392	5,761	5,761
1956	8,729	6,908	8,729	3,629	8,729	8,729
1957	6,213	4,180	6,213	1,467	6,213	6,213
1958	7,207	5,628	7,207	2,681	7,207	7,207
1959	7,096	5,957	7,096	2,433	7,096	7,096
1960	6,518	5,921	6,518	3,079	6,518	6,518
1961	4,994	4,538	4,994	1,494	4,994	4,994
1962	5,851	4,918	5,851	2,231	5,851	5,851
1963	5,954	5,186	5,954	2,494	5,954	5,954
1964	7,518	6,586	7,518	3,926	7,518	7,518
			Catch per unit (no. of fish per tan)			
1952	1.57	1.77	1.34	0.12	0.0021	4.44
1953	1.17	2.82	2.04	0.50	0.0023	5.64
1954	1.33	1.19	3.24	0.54	0.0224	5.92
1955	1.64	2.02	2.43	0.61	0.0075	5.93
1956	1.00	0.95	1.75	0.93	0.0134	3.91
1957	3.12	4.12	1.43	0.13	0.0040	7.41
1958	1.49	1.40	1.95	1.16	0.0053	4.97
1959	1.29	3.13	1.81	0.57	0.0089	5.96
1960	1.98	0.31	1.61	0.28	0.0276	4.04
1961	2.60	0.71	1.23	0.19	0.0062	4.55
1962	1.81	0.21	1.09	0.69	0.0209	3.38
1963	1.50	1.20	0.98	0.76	0.0148	3.94
1964	0.94	0.33	1.15	0.90	0.0545	2.92

[1] Statistics for 1952–60, Manzer *et al.* (1965); statistics for 1961–64 from INPFC Statistical Yearbooks. Statistics for sockeye, chum, and chinook salmon for entire season; statistics for pink salmon for June through August; statistics for coho salmon for July and August.

Sockeye Salmon

The total catch of sockeye salmon in 1964 (Table 25 and Fig. 52) was the smallest since 1955. As indicated by the catch per unit effort, the abundance of sockeye in the mothership fishing area was lower in 1964 than in any year since the post-war high seas fishery began in 1952.

Most of the 1964 catch was taken before July 1, west of long. 175°E, and after July 20, east of long. 175°E. The catch between June 21 and July 20 was very small.

In 1956, 1957, 1960, and 1961, substantial catches of sockeye salmon were made east of long. 175°E in June and as late as early July. In the other previous years, as in 1964, most of the catch in May and June was taken west of long. 175°E. In all previous years, the catches of sockeye between June 21 and July 20 were substantially greater than in 1964. Catches east of long. 175°E after July 20 were considerably greater in 1964 than in any previous year.

In May and June of 1964, sockeye salmon were more abundant west of long. 175°E than east of 175° E. In late July and early August, sockeye salmon were fairly uniformly distributed over a broad area in the Bering Sea and North Pacific Ocean (from the coast of the Kamchatka Peninsula to long. 175°W). Presumably most of the sockeye salmon in late July and early August were immature fish.

Pink Salmon

The total catch of pink salmon in 1964 (Table 25 and Fig. 53) was about 2.2 million fish, as compared with catches of about 1.0 and 1.8 million fish in 1962 and 1960. The increase in catch was due to increases in fishing effort and in abundance as reflected by the catch per unit of effort. Almost all of the pink salmon catch in 1964 was made between longs. 160° and 175°E from June 1 to July 10. Every year since 1955, except 1956, 60 to 80 percent of the total annual catch of pink salmon has been taken west of long. 175°E during the same 40-day period. The remaining 20 to 40 percent has usually been taken west of long. 175°E after July 10.

Catches of 10,000 to 20,000 pink salmon were made in late July and early August 1964 between longs. 180° and 175°W and between lats. 50°N and 52°N. The location and timing of the catches suggest that these fish originated in nearby Aleutian Island streams, but confirming evidence is lacking.

The catch-per-unit-effort statistics indicate that the abundance of pink salmon in 1964 increased somewhat over the two preceding even-numbered years, 1960 and 1962, but remained low in comparison with that of the even-numbered years preceding 1960.

The catch per unit of effort was very low over a broad area of fishing in May 1964, as it generally was during the same month in previous years, including those years in which the abundance of pink salmon later in the season was much greater than in 1964. This suggests that in May pink salmon are south of the mothership fishing area.

In the area of fishing south of lat. 54°N, beginning June 1, the centers of abundance of pink salmon were west of long. 175°E, as in most preceding years.

Chum Salmon

The catch of chum salmon in 1964 (Table 25 and

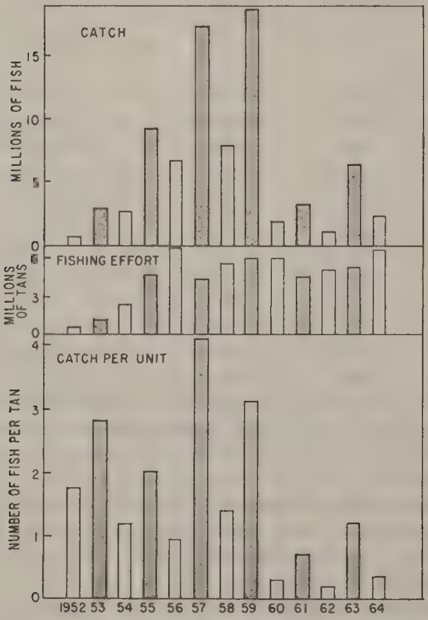

FIGURE 53. Pink salmon catch, fishing effort, and catch per unit effort, Japanese mothership salmon fishery, longs. 160°E to 175°W, 1952–64 (June-August).

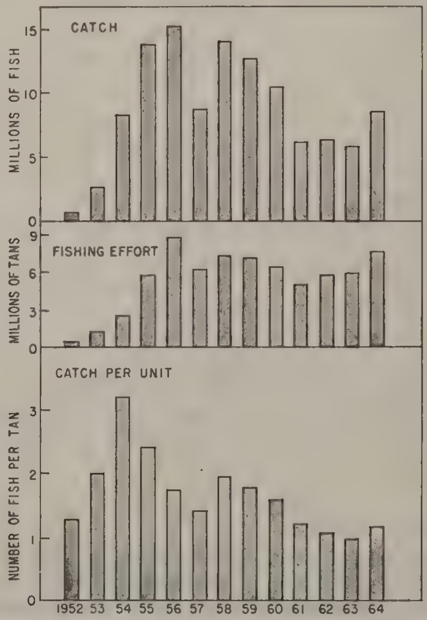

FIGURE 54. Chum salmon catch, fishing effort, and catch per unit effort, Japanese mothership salmon fishery, longs. 160°E to 175°W, 1952–64 (entire season).

Fig. 54) was greater than that of the three previous years, and exceeded the average annual catch for 1961–63 by about 2.5 million fish. The increased catch appears to have been primarily due to increased fishing effort, since the catch per unit of effort in 1964 was about the same as the average catch per unit of effort in 1961–63. Both the catch and catch per unit of effort indicate that the abundance of chum salmon in 1964 was lower than in the six or seven years preceding 1961.

About 90 percent of the chum salmon catch in May and June of 1964 was taken west of long. 175°E and south of lat. 54°N. In all other years since 1955, except 1956, over 70 percent of the May-June catch of chum salmon was made west of long. 175°E. After June 20, 1964, chum salmon catches south of lat. 54°N were generally small, but several large catches were made north of lat. 56°N, between longs. 165°E and 175°W.

Coho Salmon

The catch of coho salmon in 1964 (Table 25 and Fig. 55) was the largest on record. This was due to a combination of the greatest fishing effort on record for July and August and, as indicated by the catch-per-unit-effort data, a relatively high level of abundance.

In 1964, as in previous years, practically the entire season's catch of coho salmon was taken after July 10, south of lat. 52°N. About one-half of the 1964 catch was taken between longs. 175°E and 175°W. In previous years, except 1963, there was no fishing east of long. 175°E, south of lat. 52°N, after July 10.

In 1964 as in previous years, the catch per unit of effort for coho salmon was negligible over the entire area of fishing in May and June. Also in 1964, as in previous years, coho salmon were extremely scarce north of lat. 52°N throughout the season.

Chinook Salmon

The 1964 catch of chinook salmon (Table 25 and Fig. 56) was more than double that of any previous year. The catch per unit of effort was considerably greater than in any previous year.

Catches of chinook salmon through June 20, 1964, were small, as they generally were through the same date in previous years. In late June and early July, however, large catches were made north of lat. 56°N, east of long. 170°E. From July 11 to August 10, catches of chinook salmon were large south of lat. 52°N, east of long. 170°E.

There were large concentrations of chinook salmon

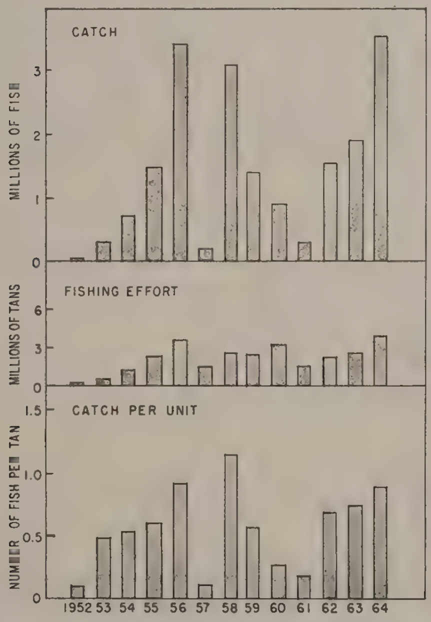

FIGURE 55. Coho salmon catch, fishing effort, and catch per unit effort, Japanese mothership salmon fishery, longs. 160°E to 175°W, 1952–64 (July-August).

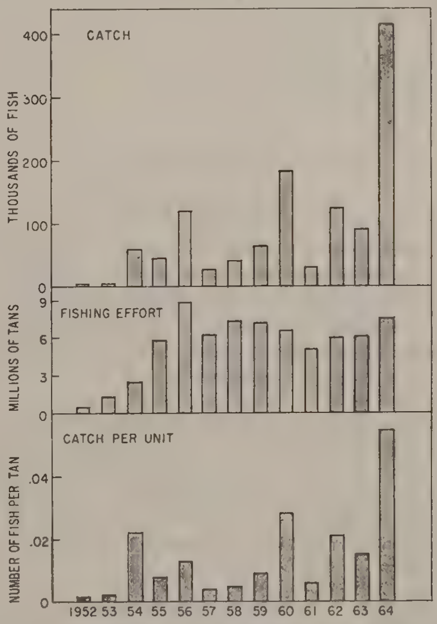

FIGURE 56. Chinook salmon catch, fishing effort, and catch per unit effort, Japanese mothership salmon fishery, longs. 160°E to 175°W, 1952–64 (entire season).

north of lat. 56°N between longs. 165°E and 175°W in late June and early July, and south of lat. 52°N between longs. 165°E and 175°W from July 11 to August 11.

Data on the average weights of chinook salmon caught by the mothership fishery in 1964 suggest that most of the fish taken north of lat. 56°N after June 20 and south of lat. 52°N after July 10 were immature.

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KING CRAB RESEARCH

by James B. Kirkwood

An agreement between the United States and Japan, which entered into force November 25, 1964, established a maximum annual commercial harvest for Japan for 1965 and 1966 and called for additional research by the two nations. The following is a quotation from the agreement:

> The International Commission under the North Pacific Fishery Convention will be asked by the two Governments to continue and intensify the study of the king crab resources in the eastern Bering Sea and to transmit to the two Governments annually by November 30 the findings of such study, including also, to the extent possible, an estimate of the maximum sustainable yield of the resource.

A summary of studies on eastern Bering Sea king crabs during 1965 by the Auke Bay Biological Laboratory follows.

A Japanese-speaking observer was stationed aboard the king crab factoryship *Dainichi Maru* and the research ship *Kumamoto Maru No. 2* for approximately two months during the summer of 1965. During this period the commercial catch of king crabs was sampled and 4,588 male crabs, selected at random, were measured and weighed. A size frequency study of these measurements shows that the crabs sampled ranged in carapace length from 122 mm to 204 mm with a mean of 152 mm (Fig. 57). The range in weight was from 1.4 kg to 5.2 kg with a mean of 2.4 kg.

U.S. scientists met with Japanese scientists near Ugashik Bay in July, aboard the Japanese research ship *Kumamoto Maru No. 2*. Research currently being conducted and plans for future research were discussed at length. There was considerable discussion concerning Soviet Union activities in the eastern Bering Sea. A large part of the research conducted by the United States and Japan in the past has been centered on tagging. The U.S.S.R. has not returned king crab tags recovered from the eastern Bering Sea since 1961, and no formal catch data have been made available. An agreement between the U.S.S.R. and the United States signed in February 1965, however, states that these data will be available to the United States in the future. There is indication that the data for past years may be available to the United States sometime during 1966.

Tag and recovery data for king crabs tagged in the Bering Sea by the United States prior to 1962 and recovered by Japan during 1965 have been received at the Auke Bay Biological Laboratory. The data show that the *Dainichi Maru* captured 138 king crabs bearing U.S. tags, and the *Tokei Maru* captured 84.

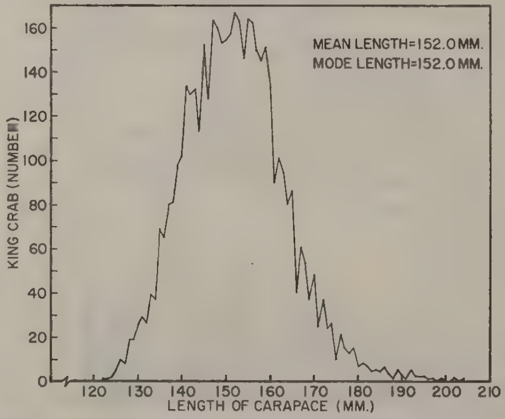

FIGURE 57. Length-frequency distribution of 4,588 male king crabs sampled in 1965 by a U.S. observer aboard the Japanese mothership *Dainichi-maru*.

The last year in which the United States tagged crabs in the eastern Bering Sea was 1961. The 1965 recovery data have not been thoroughly analyzed.

The annual catches of king crab in the eastern Bering Sea by the United States were summarized from catch statistics of the Alaska Department of Fish and Game (Table 26). The numbers of crabs shown in Table 26 may vary from numbers given in other reports because the table includes catches from U.S. territorial waters.

Two reports have been completed by the Seattle Biological Laboratory and will be submitted to the INPFC for publication. They are: *King crab of the eastern Bering Sea: a study of movement of king crabs into the commercial fishery*, by Robert R. Simpson and Herbert H. Shippen, and *Biomass relations in eastern Bering Sea king crabs, based on tagging estimates of growth and mortality*, by George Hirschhorn.

Table 26. Annual United States commercial catches of king crab in the eastern Bering Sea, 1960–65.[1]

Year	Number of crabs	Average weight (pounds)
1960	87,730	7.8
1961	61,528	10.0
1962	10,346	10.0
1963	100,728	7.7
1964	122,848	8.3
1965	223,248	7.3

[1] Includes catches in territorial waters (inside three miles of shore). Source: Alaska Department of Fish and Game.

C. INVESTIGATIONS BY THE UNITED STATES FOR THE INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION—1966

U.S. Bureau of Commercial Fisheries
Biological Laboratory, Seattle, Washington
March 10, 1967

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INTRODUCTION

Research by the United States for the International North Pacific Fisheries Commission (INPFC) in 1966 included inquiries on: (1) distribution, relative abundance, and migrations of salmon on the high seas, (2) factors influencing the westward extent and flow of the Alaskan Stream, (3) racial identification of sockeye and pink salmon by scale characteristics, (4) the use of mothership catch-effort and biological statistics for forecasting sockeye salmon runs a few weeks before they enter Bristol Bay, and (5) king crabs of the southeastern Bering Sea.

Progress on these and related investigations are summarized herein. Studies on tagging and sampling were carried out by the Fisheries Research Institute, University of Washington, under contract to the Bureau of Commercial Fisheries (BCF). Scientists of the BCF Biological Laboratory at Auke Bay, Alaska, conducted field studies on king crabs. The remainder of the work was done by the Bureau's Biological Laboratory in Seattle, Washington.

Some of these materials are updated revisions of information presented by the United States at the 1966 annual meeting of the Commission.

TAGGING AND SAMPLING

by A. C. Hartt, L. S. Smith, M. B. Dell, and R. V. Kilambi

The Fisheries Research Institute of the College of Fisheries, University of Washington, under contract to the U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, sampled and tagged salmon on the high seas in a program similar to that of 1965. The work consisted of five operations: (1) longlining in the Gulf of Alaska, (2) indexing abundance in the central Aleutian area by purse seine, (3) studies of fingerling salmon in the Gulf of Alaska by purse seine, (4) studies of fingerling salmon in the eastern Bering Sea, and (5) test of tag efficiency on rainbow trout at the College of Fisheries, Seattle. The schedule of operations by charter vessels is shown in Table 1.

Longlining in the Gulf of Alaska

The principal objective was to fish and tag over wide areas of the Gulf, starting early in the season, to compare abundance, distribution, and migration of salmon (mainly mature) in 1966 with those in earlier years. The longline sampling was coordinated with similar operations by Canada. The total Gulf program was the most comprehensive to date. Three Canadian and three United States boats repeatedly fished a grid of stations between lat. 43°N and lat. 59°N, westward to long. 170°W. Details of Canadian operations are available elsewhere in this annual report.

A total of 222 sockeye salmon was frozen and sent to the Nanaimo Biological Station, Fisheries Research Board of Canada, for racial identification by means of meristic characters and parasites. In addition, 557 pink salmon were preserved by salting and sent to Nanaimo for vertebral counts as an aid in identi-

Table 1. Schedule of operations by Fisheries Research Institute vessels in 1966, showing areas fished, gear used, and dates of fishing.

Vessel	Gulf of Alaska longlining	Eastern Bering Sea fingerling seining	Adak I. area index seining	Gulf of Alaska fingerling seining	En route Seattle fingerling seining
Commander	4/28–6/22	6/26–8/11	—	—	8/12–8/28
Storm	4/28–6/6	—	6/10–8/12	—	8/13–8/28
Harmony	5/25–7/12	—	—	7/13–9/25	—

Table 2. Numbers of salmon and steelhead caught and numbers tagged in 1966 by gear and subproject.

	Species of salmon or trout						
Subproject	Sockeye	Chum	Pink	Coho	Chinook	Steelhead	Total
Gulf longlining[1]							
Numbers caught	1,996	949	2,322	169	11	66	5,513
Numbers tagged	1,502	752	1,554	135	8	43	3,994
Adak I. index seining							
Numbers caught	1,752	3,031	489	42	16	—	5,330
Numbers tagged	1,509	787	148	6	3	—	2,453
Eastern Bering Sea fingerling seining (totals include a few mature fish)							
Numbers caught	4,883	123	60	0	15	—	5,081
Numbers tagged	298	44	52	0	8	—	402
Gulf of Alaska fingerling seining (totals include a few mature fish)							
Numbers caught	2,992	1,040	10,012	3,209	114	26	17,393
Numbers tagged	514	185	2,087	1,693	34	23	4,536
Grand total caught	11,623	5,143	12,883	3,420	156	92	33,317
Grand total tagged	3,823	1,768	3,841	1,834	53	66	11,385

[1] Includes one longline set near Adak Island and one in the eastern Bering Sea.

Table 3. Average catch of pink salmon per 20 skates of longline gear in the Gulf of Alaska compared to the commercial catch in Gulf coastal areas—1962, 1964, and 1966.

	1962		1964		1966	
Period	Mean catch[1]	No. of areas[2]	Mean catch	No. of areas	Mean catch	No. of areas
April 1–May 15	13.1	(32)	21.9	(19)	5.4	(34)
May 16–31	30.9	(20)	26.9	(17)	11.4	(23)
June 1–15	66.5	(15)	45.0	(6)	17.5	(17)
June 16–30	81.6	(18)	129.5	(6)	38.3	(19)
July 1–15	88.6	(9)	74.8	(4)	62.6	(9)
Longline mean	*56.1*		*59.6*		*27.0*	
Commercial catch[3] (in millions of fish)	64.3		53.1		54.7	

[1] Mean adjusted catch of pink salmon per 20 skates for all areas in which data for two or three years were available—Canadian and U.S. data.

[2] 2° × 5° statistical areas in which fishing was conducted in two or three years.

[3] Pink salmon catch for British Columbia, southeastern Alaska, and central Alaska (1966 figures preliminary).

fication. The Nanaimo Station kindly loaned a brine freezer and cold storage boxes for installation on the vessel *Storm*.

In general, the catches in 1966 indicated distribution and seasonal migration similar to those of earlier years. The numbers of fish caught and tagged by U.S. vessels are listed in Table 2.

Mature sockeye salmon were most abundant in the northwestern and north-central Gulf (north of lat. 50°N and west of long. 140°W) in April and May; many appeared to shift westward as the season progressed. Scale examinations showed a high proportion of fish of Bristol Bay type in the northwestern Gulf. Tag returns verified the importance of Bristol Bay stocks in this area.

Mature chum salmon were dispersed widely and showed little evidence of concentration throughout the sampling period. Immature chum and sockeye salmon occurred mainly in the southern half of the Gulf, and shifted northward later in the season.

Pink salmon were located during the early season in the southern part of the Gulf, mainly between lat. 43°N and lat. 52°N; they were most abundant east of long. 145°W. As in previous years, pink salmon shifted northward as the season progressed. Catches began to increase in the northwestern part of the

Gulf by late June and early July, indicating a movement in that direction. The average catch per longline skate (49 hooks) in 1966 was deceptively low in relation to the actual abundance as measured in the subsequent coastal catch (Table 3). In all three cycle years 1962, 1964, and 1966, the seasonal increase in abundance or " availability " was evident, but the average longline catch of 27.0 in 1966 was much too low with respect to the relative coastal catches for the three years. The disparity was particularly pronounced in the early part of the season. During the final (July 1–15) sampling period the 1966 average catch increased considerably relative to 1962 and 1964, and gave an indication that the early-season index was too low. Data were too few after July 15 for a comparison. As a whole, the data in Table 3 cast considerable doubt on the reliability of the present method of longline indexing.

Tag returns from the Gulf longlining in general showed a distribution similar to that of earlier years. For a complete description of the results, returns from Canadian and United States operations would have to be considered together, because the vessels from the two countries operated in a joint grid pattern. An outstanding new feature was the recovery in Southeastern Alaska of three pink salmon that had been tagged on May 26 near Cape Flattery, Washington (lat. 48°25′N, long. 125°08′W). The returns extend the known eastern limit of Southeastern Alaska pink salmon by about 5° of longitude and suggest that this stock in 1966 was oriented farther east than usual. Another new feature was the recovery on Iturup Island in the Kuril group of two chum salmon that had been released at lat. 48°30′N, long. 141°30′W in the south-central Gulf of Alaska. Both were released and recovered in 1964, but recovery data were not received from the U.S.S.R. until 1966. These returns extend the known eastern limit of Kuril Island stocks by about 10° of longitude.

Indexing Abundance in the Central Aleutian Area

The main objective of the work in the central Aleutian area was to obtain an index of the abundance and age composition of immature sockeye salmon on which to base a forecast of the 1967 run to Bristol Bay.

The vessel *Storm* seined south of Adak Island from June 10 to August 12. The operation was coordinated with the gillnetting by the U.S. Bureau of Commercial Fisheries chartered vessel *Paragon;* a series of comparative catches from the two types of gear was obtained. Comparative sets were made inshore and offshore in areas of abundance and scarcity.

Immature sockeye salmon passed westward south of Adak Island throughout the period of sampling. The younger .1 age group was more abundant than the .2 age group.[1] The data are being incorporated into a consolidated forecast to be published by the Alaska Department of Fish and Game in the winter of 1967.

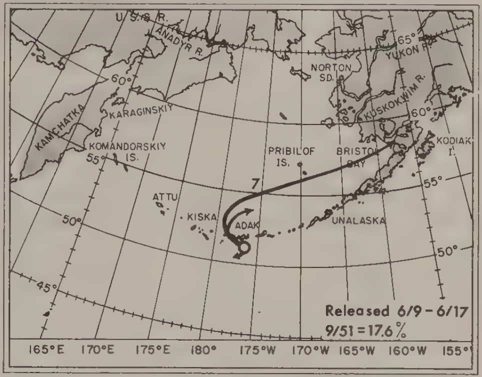
U.S.S.R.
ANADYR R.
65°
YUKON R.
NORTON SD.
KUSKOKWIM R.
60°
KARAGINSKIY
KAMCHATKA
KOMANDORSKIY IS.
55°
PRIBILOF IS.
BRISTOL BAY
KODIAK I.
55°
7
ATTU
KISKA
ADAK
UNALASKA
50°
50°
45°
Released 6/9 – 6/17
9/51 = 17.6 %
165°E
170°E
175°E
180°
175°W
170°W
165°W
160°W
155°

Figure 1. Recovery distribution of nine sockeye salmon tagged in area 8050 in 1966.

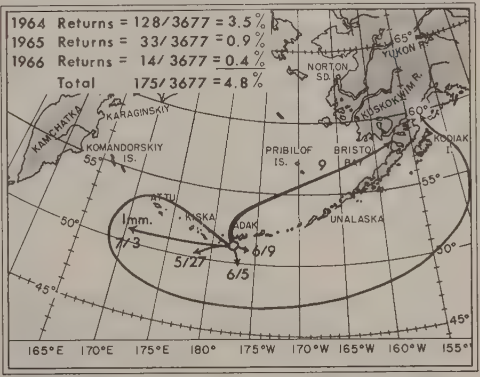
1964 Returns = 128/3677 = 3.5 %
1965 Returns = 33/3677 = 0.9 %
1966 Returns = 14/3677 = 0.4 %
Total 175/3677 = 4.8 %
65°
YUKON R.
NORTON SD.
KUSKOKWIM R.
60°
KARAGINSKIY
KAMCHATKA
KOMANDORSKIY IS.
55°
PRIBILOF IS.
9
BRISTOL BAY
KODIAK I.
55°
ATTU
KISKA
ADAK
UNALASKA
Imm.
7/3
5/27
6/5
6/9
50°
50°
45°
45°
165°E
170°E
175°E
180°
175°W
170°W
165°W
160°W
155°

Figure 2. Recovery distribution of 14 sockeye salmon (.1 age) tagged in area 8050 in 1964 and recovered in 1966.

---

[1] Scales were used to determine age of salmon, and age designations in all sections of the report on United States research follow the formulas of Koo (1962). The number of winters at sea is shown by an Arabic numeral preceded by a dot; similarly, the number of winters that the adult salmon spent in fresh water (not counting the winter the egg was in gravel) is shown by an Arabic numeral preceding a dot. Both are shown by two Arabic numerals separated by a dot. An age designation of 1.2 corresponds to age 4_2 in the formula of Gilbert and Rich (1927) that was previously used in reports on United States research.

Immature chum salmon were also prominent in the catches throughout the sampling. Mature pink salmon were present in moderate and diminishing numbers through late June, which is typical for an even-numbered year.

The 51 mature sockeye salmon tagged in area 8050 yielded nine returns (17.6 percent) as illustrated in Figure 1. Distribution of recoveries was similar to that in previous years. This rate of return of sockeye salmon released in area 8050 is the highest since operations began in 1956.

Fourteen sockeye salmon tagged as .1 age immatures in 1964 were returned in 1966 (Figure 2). Four were from the high seas, nine from Bristol Bay, and one from Cook Inlet. Past experience suggests that the three recovered near the central Aleutians were probably destined for Bristol Bay. The continental destination of the one recovered near long. 170°E cannot be inferred, because it was judged immature by gonad weight (female, 18 g). The return rates of 0.4 percent in 1966, 0.9 percent in 1965, and 3.5 percent in 1964 indicate a relatively good survival of the .1 age immature fish tagged at Adak Island in 1964. In contrast, the rate of return in 1966 of .1 age sockeye salmon tagged at Adak Island in 1965 was only 0.06 percent (Figure 3). The lack of 1965 high seas returns from the 1965 experiments was due to early termination of fishing by the mothership fleet.

As is shown in Figure 3, 26 returns in 1966 were from releases of immature sockeye salmon at Adak Island in 1965. Twenty were from Bristol Bay, two from the Cape Lutke fishery south of Unimak Island, and four from the high seas. The latter were probably destined for Bristol Bay. The two recovered at Cape Lutke were probably also en route to Bristol Bay. The Cape Lutke fishery operates mainly on westerly migrating sockeye salmon, most of which are ultimately destined for Bristol Bay. These two recoveries further indicate that some of the immature sockeye salmon that migrated westward past Adak Island in 1965 returned far to the east before the summer of 1966 and again passed westward en route to Bristol Bay.

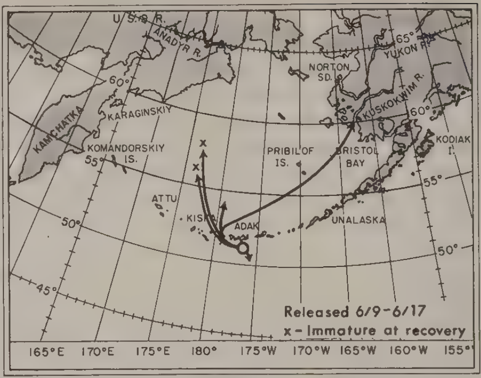
U.S.S.R.
ANADYR R.
65°
YUKON R.
NORTON SD.
KUSKOKWIM R.
60°
KAMCHATKA
KARAGINSKIY
KOMANDORSKIY IS.
55°
PRIBILOF IS.
BRISTOL BAY
KODIAK I.
ATTU
KISKA
ADAK
UNALASKA
50°
45°
Released 6/9–6/17
x – Immature at recovery
165°E 170°E 175°E 180° 175°W 170°W 165°W 160°W 155°

FIGURE 4. Recovery distribution of five chum salmon tagged in area 8050 in 1966.

As is illustrated in Figure 4, five chum salmon were recovered from those released in 1966. It is not practical to estimate rates of return for chum salmon until maturity data have been analyzed. Two were classified as immature at recovery (on the basis of gonad weights). The recovery from the Kuskokwim River was rather unusual since chum salmon tagged west of long. 175°W yield very few North American recoveries. Asian coastal returns from tagging in area 8050 are expected in the future.

The 165 mature pink salmon tagged in area 8050

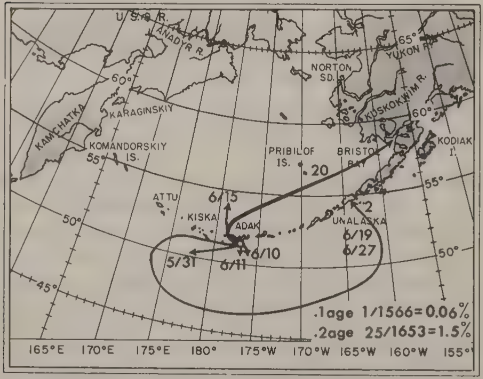
U.S.S.R.
ANADYR R.
65°
YUKON R.
NORTON SD.
KUSKOKWIM R.
60°
KAMCHATKA
KARAGINSKIY
KOMANDORSKIY IS.
55°
PRIBILOF IS.
20
BRISTOL BAY
KODIAK I.
ATTU
KISKA
ADAK
6/15
UNALASKA
2
6/19
6/27
6/10
5/31
6/11
50°
45°
.1age 1/1566=0.06%
.2age 25/1653=1.5%
165°E 170°E 175°E 180° 175°W 170°W 165°W 160°W 155°

FIGURE 3. Recovery distribution of 26 sockeye salmon tagged in area 8050 in 1965 and recovered in 1966.

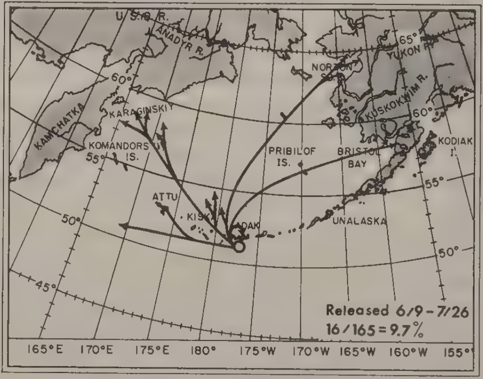
U.S.S.R.
ANADYR R.
65°
YUKON R.
NORTON SD.
KUSKOKWIM R.
60°
KAMCHATKA
KARAGINSKIY
KOMANDORSKIY IS.
55°
PRIBILOF IS.
BRISTOL BAY
KODIAK I.
ATTU
KISKA
ADAK
UNALASKA
50°
45°
Released 6/9–7/26
16/165=9.7%
165°E 170°E 175°E 180° 175°W 170°W 165°W 160°W 155°

FIGURE 5. Recovery distribution of 16 pink salmon tagged in area 8050 in 1966.

yielded 16 returns; five from western Alaska, two from the Aleutian Islands, and ten from the high seas (Figure 5). Coastal returns from Karaginskiy (E. Kamchatka) are expected in the future. The distribution of the recoveries is typical for recent even-numbered years which are off-cycle years for East Kamchatka and cycle years for western Alaska and the Aleutian Islands. The recovery rate of 9.7 percent[2] is the best experienced to date for the Adak Island area.

Studies of Fingerling Salmon in the Gulf of Alaska

A fine-meshed purse seine was used to collect samples for studying the distribution, abundance, migrations, length, and growth of .0 age fingerling salmon of all species from Cape Flattery (lat. 48°N) to Yakutat (lat. 59°N). Secondary objectives were (1) to test two types of tags for young salmon, (2) to study feeding habits of fingerling salmon during early ocean residence, and (3) to continue studies of the effects of handling and tagging injuries, particularly scaling. The vessel *Harmony* began these operations on July 13 and continued through September 25. The vessels *Commander* and *Storm*, while returning to Seattle from their western fishing stations, supplemented the sampling by fishing along the coastline from the Shumagin Islands to the Strait of Juan de Fuca. The following inner channels were fished in 1966 for comparison with samples taken on the outer coastline: (1) San Juan Islands, (2) Strait of Juan de Fuca, (3) north entrance of Johnstone Strait, (4) Dixon Entrance, (5) Sumner Strait, (6) Chatham Strait, and (7) Icy Strait.

Seine catches in 1966 confirmed observations in 1964 and 1965 that fingerling salmon remain primarily within 20 miles of shore and move predominantly northward along the coasts of Washington, British Columbia, and Southeastern Alaska. Individuals taken in the inner channels were generally smaller than those taken on the outer coast.

Forty coho salmon and five pink salmon were returned in 1966 from releases of tagged fingerlings in 1965 (Figure 6). All recovery locations were south of the release points; these fish clearly had moved northward in the summer of 1965 before they were tagged. Their routes to the recovery locations most likely followed a circuitous course around the Gulf of Alaska Gyre.

Coho salmon were expected to give a higher rate of return (3.8 percent) than pink salmon (0.2 percent) because the coho salmon were considerably larger at the time of tagging.

It is possible now to make a rough comparison of return efficiency between the tags used on fingerlings in 1964 and 1965 as shown below:

Year tagged	*Type of tag*	*Coho salmon returns*	*Pink salmon returns*
1964	Plastic dart	6/368=1.6%	0/1018=0.0%
1965	Carlin dangler, Knotted tube Disc	40/1062=3.8%	5/2671=0.2%

Apparently the tags used in 1965 were more efficient than the dart tags used in 1964. Returns in 1966 were too few for a critical comparison of the three types used in 1965. It is hoped that sockeye and chum salmon from the 1965 releases will be returned in 1967. In view of the improved coho and pink salmon returns in 1966 at least a few returns of the other species may be expected. The Carlin tag and the knotted tube tag were again used in 1966.

The studies of the effects of scale loss on fingerling salmon begun in 1965 were continued in 1966 aboard the seiner *Harmony*. The effects of scale loss—increasing lethargy, blood dilution from escaping tissue fluids, probably a progressive decline in heart function, and decreased urine production—resemble traumatic shock in humans after severe burn. The 1966 work was designed to describe more exactly the imbalances which occur in fluid and electrolyte dynamics of injured fish and to develop remedial procedures to alleviate these symptoms. Preliminary experiments to test a possible remedy for tagging injuries indicated that fish with a severe scale loss survive 2–3 times longer after injury when kept for 30–60 minutes in dilute sea water than when kept in fresh water or normal sea water. Presumably the improved survival is due to the increased ease with which the fish can regulate blood volume and electrolyte levels. Although the fish in these experiments eventually died, the increase in the length of their survival warrants a thorough testing of diluted sea water as a recovery medium. Future physiological work will be done aboard a laboratory barge which will be towed to the research and tagging sites.

Studies of Fingerling Salmon in the Eastern Bering Sea

The objectives were to study the distribution, migrations, timing, feeding, and growth of fingerling salmon of all species, but particularly of sockeye salmon, as they enter the ocean from Bristol Bay. The vessel *Commander* was engaged in this work. Fishing was conducted with a fine-meshed purse seine from June 26 to August 11 mainly on a line between Cape

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[2] The total of pink salmon releases in the Adak Island area in Table 2 (148) is not in agreement with the total in Figure 5 (165) because the latter includes 17 pink salmon tagged from longline catches.

Newenham and Port Moller. Additional exploratory sets were made farther westward toward the Pribilof Islands and Unalaska Island. Work was coordinated with activities closer to Bristol Bay by U.S. Bureau of Commercial Fisheries personnel from the Auke Bay Biological Laboratory.

Catches showed fingerling sockeye salmon were present in a rather narrow belt within 20 or 30 miles of the north side of the Alaska Peninsula and extending from about long. 160°W to long. 163°30′W. Catches varied from only a few fish to 1,300 per set. The average size of the sockeye salmon fingerlings varied from 11.5 cm to 18 cm and increased as the season progressed. Sets of the seine faced in opposite directions indicated that fish were migrating along the coast in both directions. Because the larger catches were made with the seine open to the northeast, net movement was probably southwestward along the coast. No fingerling sockeye salmon were taken either in sets made more than 30 miles offshore or close to the north shore off Cape Newenham. In contrast, exploratory seining in 1962 yielded fingerlings at points 75 miles north of the north side of the Alaska Peninsula. Very few salmon species other than sockeye were caught in 1966 ; a few fingerling chinook and chum salmon were taken. In general, the results suggested that through mid-August the fingerling sockeye salmon remained primarily in the Bering Sea and moved about in waters very close to the Alaska Peninsula. Future work to discover the offshore migrations of fingerling salmon in this area should continue later in the season.

Large numbers of euphausiids and larval fish were frequent in the seine. Jellyfish were also very abundant in most of the catches in the eastern Bering Sea; typical specimens were large and brown with long, trailing tentacles. Stomach contents of the fingerling sockeye salmon were predominantly euphausiids and larval fish.

Only 137 sockeye salmon fingerlings were tagged in the Bering Sea in 1966 because emphasis was mainly on exploring distribution and abundance.

Tag Efficiency Test on Rainbow Trout at the College of Fisheries, Seattle

The objective of this experiment was to test the retention and detection of two tags which are being used on young salmon at sea, from which short-term and long-term recoveries are expected. Long-term recoveries are particularly sought in order that the condition of the wound and effect of overgrowth can be examined.

The fish were kindly made available by Dr. Lauren Donaldson of the College of Fisheries, University of Washington. The fish were tagged on February 28 and March 1 at the College of Fisheries ponds, and released directly into Lake Union adjacent to the effluent from the rearing ponds.

Table 4 lists pertinent release data and recovery data through January 15, 1967. Most recoveries were from Lake Union and Lake Washington within one or two miles of the point of release, but some returns came from as far away as the Sammamish River at the north end of Lake Washington and from the lower Lake Washington ship canal near the Ballard locks. All recoveries were by sport fishing gear.

Tag return efficiency through January 15 was similar for the Carlin and disc tags (50.1 percent and 52.4 percent, respectively). It is hoped that sufficient tagged fish are still at liberty for returns after 12–24 months to be compared.

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Koo, Ted S. Y. 1962. Age designation in salmon. *In: Studies of Alaska Red Salmon.* Univ. of Washington Press, Seattle, pp. 39–48.

OCEAN DISTRIBUTION, ABUNDANCE, AND MIGRATIONS OF SALMON

by R. French, D. Craddock, R. Bakkala, J. Dunn, and K. Thorson

Four research cruises in 1966 continued our study of the distribution, abundance, and migrations of salmon on the high seas (Figure 7). In June and early July, fishing in the eastern Bering Sea provided information on the distribution, size and age compositions, and timing of the 1966 return of sockeye salmon to Bristol Bay. The objectives of the three cruises in the North

Table 4. Data on tag-efficiency tests, College of Fisheries, University of Washington.

Date of tagging	Species of trout	Length range (cm)	Type of tag	Number released	Number recovered (through 1/15/67)	Percentage recovered
2/28/66	Rainbow-steelhead hybrids	23–37	Carlin	146	74	50.1
2/28/66	Rainbow-steelhead hybrids	23–37	½″ disc (white)	147	77	52.4
3/1/66	Rainbow	28–40	½″ disc (white)	362	147	40.6

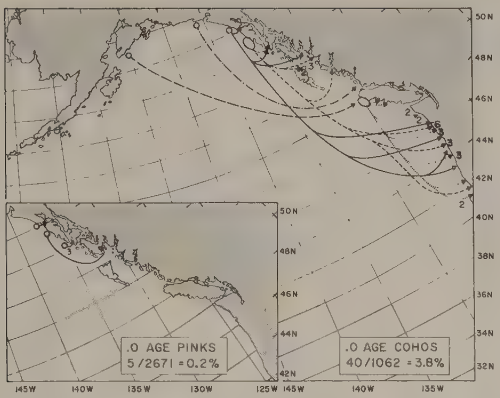

FIGURE 6. Recovery distribution of 40 coho and five pink salmon tagged in 1965 and recovered in 1966. Lines from each tagging location are drawn variously for clarity; no other significance applies.

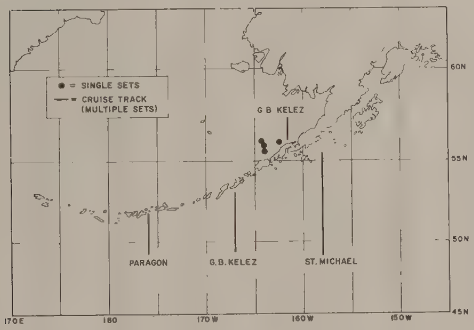

FIGURE 7. Areas fished by U.S. vessels *George B. Kelez*, *Paragon*, and *St. Michael*, June–September 1966.

Pacific Ocean in July-September were: (1) to study the distribution and relative abundance of immature sockeye and chum salmon, (2) to compare indices of relative abundance from catches of gill nets and purse seines fished simultaneously, and (3) to determine the percentage of salmon lost from gill nets during fishing (dropouts).

DISTRIBUTION AND ABUNDANCE

Eastern Bering Sea

In mid-June the research vessel *George B. Kelez* was diverted from mortality studies in the North Pacific Ocean to the eastern Bering Sea to provide information on the relative numbers and timing of the incoming return of sockeye salmon to Bristol Bay. A string of gill nets was fished 12 hours each night;

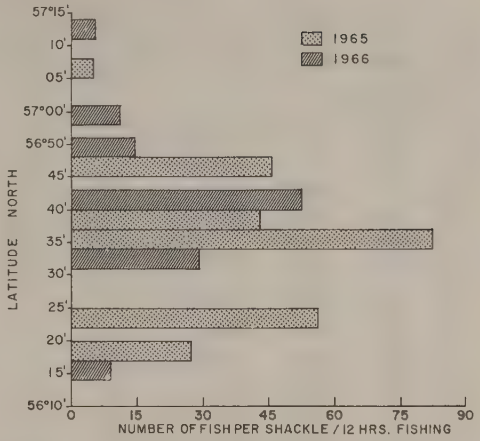

FIGURE 8. North-south distribution of sockeye salmon in the Bering Sea along approximately long. 161°30′W, June 24–July 6, 1965 and 1966.

it contained 14 shackles (each 50 fathoms long, 4 fathoms deep) of 4½-inch mesh and six shackles of 5¼-inch mesh. After a very large catch (Set No. 5, Table 5), we reduced the fishing gear to five shackles each of the two mesh sizes.

Catch data are listed in Table 5 (*George B. Kelez*, sets 1–18). Relatively few salmon were taken June 20–23 in the first four sets. The large catch from lat. 56°39′N and long. 161°30′W indicated a concentration of sockeye salmon in that area. Repeated sets were then made along approximately the same longitude for the remainder of the cruise. The catch per unit of effort decreased north and south of lat. 56°39′N (Figure 8). The distribution was similar in 1965 (French, Craddock, and Dunn, 1967). Catches were typically smaller in 1966 than in 1965; this difference reflects the smaller return of sockeye salmon to Bristol Bay this year.

The time at which the incoming run first reached the area is not known because the catch per unit of effort was highest, 54.0, when the vessel arrived on June 24. It was 29.1 on July 6, and then did not exceed 7.4 during July 7–9, by which time the peak of the return evidently had passed this area.

North Pacific Ocean

Fishing in the North Pacific Ocean by the vessels *Paragon*, *George B. Kelez*, and *St. Michael* was by gill nets of 2½-inch, 3¼-inch, 4½-inch, and 5¼-inch mesh, stretched measure. Typically, a string of gear consisted of 12 or 14 shackles of the smaller two mesh sizes and 12 or 16 of the larger two. Minor variations occurred among the three vessels in the amount of

TABLE 5. Catches of salmon and steelhead trout by United States research vessels, 1966.

Set no.	Date	Lat. N	Long. W	Surface temp. (°C)	No. of shackles	Sock-eye	Chum	Pink	Coho	Chi-nook	Steel-head	Total fish
RV *George B. Kelez*												
1	6/20	55°35′	163°57′	6.0	20	2	1	0	0	0	0	3
2	6/21	55°49′	163°59′	—	20	3	1	0	0	0	0	4
3	6/22	55°55′	164°00′	6.2	20	6	0	0	0	0	0	6
4	6/23	56°00′	162°28′	6.3	20	12	1	0	0	0	0	13
5	6/24	56°39′	161°30′	6.3	20	1,080	100	0	0	3	0	1,183
6	6/25	57°00′	161°29′	5.8	10	120	55	0	0	3	0	178
7	6/26	56°41′	161°29′	5.7	10	507	31	0	0	1	0	539
8	6/27	56°14′	161°28′	6.3	10	41	1	0	0	0	0	42
9	6/28	56°19′	161°30′	5.5	10	149	5	0	0	0	0	154
10	6/29	56°41′	161°30′	4.8	10	162	12	0	0	0	0	174
11	6/30	56°50′	161°30′	5.2	10	143	7	0	0	2	0	152
12	7/1	57°00′	161°30′	5.1	10	66	3	1	0	0	0	70
13	7/2	57°10′	161°30′	4.8	10	44	11	1	0	0	0	56
14	7/3	56°39′	161°30′	3.8	10	378	38	4	0	0	0	420
15	7/6	56°30′	161°29′	4.1	10	291	35	26	0	0	0	352
16	7/7	56°35′	161°30′	4.1	10	74	18	5	0	1	0	98
17	7/8	56°45′	161°30′	4.8	10	61	11	10	0	0	0	82
18	7/9	56°40′	161°30′	5.8	10	68	18	31	0	0	0	117
Total					230	3,207	348	78	0	10	0	3,643
RV *George B. Kelez*												
19	7/14	53°00′	167°00′	7.7	30	0	9	0	0	0	0	9
20	7/15	52°00′	167°00′	8.8	30	88	48	10	3	0	1	150
21	7/16	51°00′	166°59′	8.4	30	36	83	7	14	0	5	145
22	7/17	50°00′	167°00′	8.8	30	18	55	2	2	0	3	80
23	7/18	49°00′	167°01′	9.7	30	6	1	0	29	0	2	38
24	7/20	51°30′	166°59′	9.2	30	51	68	6	12	0	1	138
25	7/21	52°30′	167°02′	9.1	30	85	78	4	6	0	6	179
26	7/23	52°57′	167°01′	8.0	30	30	65	3	2	0	0	100
27	7/24	52°00′	167°00′	9.1	30	198	52	6	9	0	1	266
28	7/25	51°00′	166°58′	9.5	30	37	28	1	5	2	6	79
29	7/26	49°57′	167°00′	9.4	30	7	100	3	19	2	4	135
30	7/27	49°30′	167°01′	9.6	30	25	75	0	11	0	1	112
31	7/28	50°30′	166°56′	9.8	30	28	147	0	14	0	2	191
32	7/29	51°31′	167°00′	9.8	30	41	83	3	7	0	3	137
33	7/31	52°31′	167°00′	9.5	30	237	169	0	3	4	6	419
34	8/1	52°00′	167°00′	9.4	30	133	88	0	0	2	10	233
35	8/2	53°00′	167°00′	8.6	30	23	255	11	5	0	0	294
36	8/7	52°30′	167°00′	9.9	30	136	165	2	2	1	10	316
37	8/8	51°30′	167°00′	9.6	30	134	173	0	0	0	0	307
38	8/9	50°30′	167°00′	9.1	30	103	156	3	4	0	4	270
39	8/10	49°33′	167°02′	10.6	30	22	33	0	1	0	2	58
40	8/11	49°00′	166°59′	10.6	30	19	24	0	0	0	0	43
41	8/12	50°01′	167°07′	10.3	30	51	85	0	2	1	5	144
42	8/13	51°00′	166°59′	10.0	30	153	187	1	0	0	2	343
43	8/14	51°59′	166°58′	10.2	30	81	92	0	0	0	6	179
44	8/15	53°00′	167°00′	10.3	30	37	101	1	3	0	0	142
45	8/16	52°30′	166°59′	10.4	30	21	39	0	0	0	7	67
46	8/17	51°30′	167°00′	10.0	30	117	144	0	0	0	1	262
47	8/18	50°28′	167°00′	10.4	30	170	131	0	0	0	1	302
48	8/19	49°29′	167°00′	10.6	30	19	40	0	0	0	1	60
49	8/20	50°00′	167°00′	10.0	30	61	34	0	0	0	3	98
50	8/21	50°59′	166°56′	9.7	30	36	16	0	0	0	2	54
51	8/22	51°48′	166°45′	10.2	30	70	17	0	0	0	1	88

TABLE 5. Continued.

Set no.	Date	Lat. N	Long. W	Surf. temp. (°C)	No. of Shackles	Sock-eye	Chum	Pink	Coho	Chi-nook	Steel-head	Total fish
RV *George B. Kelez*												
52	8/23	53°00′	167°00′	10.4	30	93	82	0	5	3	0	183
53	8/29	52°31′	167°00′	10.3	30	14	13	0	1	0	4	32
54	8/30	51°28′	166°55′	9.0	30	68	6	0	0	0	1	75
55	8/31	50°30′	166°59′	9.8	30	111	17	0	0	0	4	132
56	9/1	49°30′	167°01′	9.8	30	87	49	0	0	1	1	138
57	9/2	49°02′	167°04′	10.7	30	35	151	0	0	0	2	188
58	9/3	50°00′	167°00′	10.3	30	83	65	0	0	0	3	161
	Total				1,200	2,764	3,224	63	159	16	111	6,337
MV *Paragon*												
1	6/26	51°30′	176°25′	5.5	28	1	0	0	0	0	0	1
2	6/27	51°15′	176°22′	7.1	28	1	0	0	0	0	0	1
3	6/28	51°00′	176°22′	7.2	28	117	99	17	1	0	0	234
4	6/29	50°45′	176°22′	6.8	28	121	28	4	1	0	0	154
5	6/30	50°30′	176°25′	7.3	28	69	28	18	0	0	0	115
6	7/1	50°15′	176°22′	7.4	28	38	52	10	0	0	0	100
7	7/2	50°00′	176°22′	7.4	28	27	54	12	0	0	2	95
8	7/6	51°28′	176°22′	5.7	28	0	1	0	0	0	0	1
9	7/7	51°15′	176°22′	7.5	28	131	9	2	0	0	0	142
10	7/9	51°00′	176°22′	7.6	28	441	307	17	1	0	0	766
11	7/10	50°45′	176°22′	7.6	24	52	75	9	2	1	1	140
12	7/11	50°30′	176°22′	7.5	28	27	79	10	3	0	1	120
13	7/12	50°15′	176°22′	7.7	28	23	209	18	7	2	0	259
14	7/13	50°00′	176°22′	7.8	28	11	24	11	36	1	1	84
15	7/14	50°22′	176°22′	8.1	28	20	80	9	23	1	0	133
16	7/15	50°37′	176°22′	8.5	28	32	39	11	9	0	0	91
17	7/16	50°52′	176°22′	8.5	28	51	30	0	6	0	0	87
18	7/17	51°07′	176°22′	8.5	28	102	18	11	2	0	0	133
19	7/18	51°22′	176°22′	8.5	28	1	0	0	0	0	0	1
20	7/21	51°30′	176°22′	8.7	28	4	0	0	0	0	0	4
21	7/22	51°15′	176°22′	9.0	28	106	33	5	4	0	0	148
22	7/23	51°00′	176°22′	9.0	28	96	52	4	21	0	0	173
23	7/24	51°30′	176°22′	9.2	28	267	125	8	33	0	0	433
24	7/25	51°15′	176°22′	9.7	28	221	21	4	10	0	0	256
25	7/26	51°00′	176°22′	9.7	28	99	32	3	15	0	1	150
26	7/27	50°45′	176°22′	9.6	28	209	57	4	35	0	1	306
27	7/28	50°30′	176°22′	9.6	28	56	33	3	15	0	1	108
28	7/29	50°15′	176°22′	9.9	28	41	47	0	36	4	7	135
29	8/1	51°30′	176°22′	9.6	28	5	0	0	0	1	0	6
30	8/2	51°15′	176°22′	9.3	28	9	0	0	0	0	0	9
31	8/3	51°00′	176°22′	9.9	28	26	7	0	1	1	0	35
32	8/4	51°15′	176°22′	9.5	28	4	0	0	0	0	0	4
33	8/5	50°45′	176°22′	10.2	28	60	5	1	13	2	0	81
34	8/6	50°30′	176°22′	10.0	28	8	4	0	2	1	5	20
35	8/7	50°15′	176°22′	9.6	28	34	9	0	3	1	0	47
36	8/8	51°15′	176°22′	8.7	28	306	20	4	7	0	0	337
37	8/11	51°30′	176°22′	9.4	28	67	72	0	3	0	0	142
38	8/12	51°15′	176°22′	10.2	28	118	39	0	3	1	4	165
39	8/13	51°00′	176°22′	9.9	28	3	1	0	0	1	0	5
40	8/14	50°45′	176°22′	9.7	28	26	12	0	0	1	4	43
41	8/15	50°30′	176°22′	10.0	28	4	2	0	0	0	0	6
42	8/16	50°15′	176°22′	10.3	28	127	25	0	1	10	6	169
43	8/17	50°00′	176°22′	10.2	28	73	30	0	1	2	4	110
44	8/18	49°45′	176°22′	10.4	28	14	6	0	0	0	0	20

TABLE 5. Continued.

Set. no.	Date	Late. N	Long. W	Surf. temp. (°C)	No. of Shackles	Sock-eye	Chum	Pink	Coho	Chi-nook	Steel-head	Total fish
MV *Paragon*												
45	8/19	49°30′	176°22′	10.4	28	6	18	0	1	1	5	31
46	8/20	51°00′	176°22′	10.2	28	40	32	0	0	0	2	74
47	8/24	51°30′	176°22′	8.3	28	3	5	0	0	0	0	8
48	8/25	51°15′	176°22′	10.0	28	42	2	0	0	0	1	45
	Total				1,340	3,339	1,821	195	295	31	46	5,727
MV *St. Michael*												
1	7/8	54°00′	158°00′	8.3	30	42	31	8	2	0	0	83
2	7/10	53°00′	158°00′	7.8	30	48	12	0	0	0	1	61
3	7/14	52°00′	158°00′	8.2	30	68	68	4	0	0	5	145
4	7/15	51°07′	158°00′	8.4	30	17	135	21	0	0	1	174
5	7/17	50°00′	158°00′	8.8	26	20	23	19	5	0	3	70
6	7/18	49°30′	158°00′	9.8	24	16	21	10	5	1	2	55
7	7/19	50°37′	158°01′	9.4	24	10	7	7	9	1	1	35
8	7/20	51°30′	157°58′	8.8	24	29	25	4	6	1	1	66
9	7/21	52°32′	158°00′	8.7	24	144	30	6	2	0	2	184
10	7/22	53°30′	158°00′	9.3	24	39	121	26	3	0	3	192
11	7/23	54°32′	158°00′	10.0	24	62	60	20	5	0	0	147
12	7/24	55°07′	158°00′	10.0	24	3	3	4	1	0	0	11
13	7/29	54°00′	158°00′	10.0	24	17	34	2	0	0	1	54
14	7/30	53°00′	158°00′	9.2	24	44	75	4	3	1	1	128
15	8/1	52°30′	158°00′	9.0	24	113	67	0	1	1	2	184
16	8/2	51°45′	158°00′	9.0	24	126	169	2	1	0	4	302
17	8/6	54°00′	158°00′	10.0	24	49	140	2	7	3	3	204
18	8/8	53°10′	158°24′	9.0	24	26	33	0	1	0	4	64
19	8/9	52°10′	158°36′	9.2	24	180	45	0	1	0	1	227
20	8/10	51°10′	158°45′	9.5	24	117	102	0	0	0	1	220
21	8/11	50°10′	158°48′	9.9	24	32	116	0	0	0	1	149
22	8/12	49°30′	158°00′	10.0	24	22	74	0	1	0	0	97
23	8/15	51°30′	157°50′	9.3	24	81	60	0	0	0	4	145
24	8/16	52°30′	157°57′	9.3	24	44	6	0	2	0	2	54
25	8/17	53°28′	157°55′	9.8	24	10	27	0	0	0	1	38
26	8/18	54°00′	158°00′	10.0	24	4	39	0	6	0	2	51
27	8/24	52°57′	158°00′	9.5	24	3	14	0	0	0	2	19
28	8/25	52°00′	158°00′	9.9	24	40	32	0	0	0	5	77
29	8/26	51°05′	158°00′	10.0	24	173	180	0	0	0	0	353
30	8/31	53°00′	158°10′	8.8	24	4	1	0	0	0	3	8
31	9/1	51°40′	158°00′	9.0	24	62	8	0	0	0	9	79
	Total				770	1,645	1,758	139	61	8	65	3,676

gear fished.

Catches (Table 5) showed that sockeye salmon were predominant near Adak Island (*Paragon*), whereas chum salmon dominated along long. 167°W (sets 19–58, *George B. Kelez*) and long. 158°W (*St. Michael*).

The average catch per shackle, derived from the number of small fish (.1 age sockeye salmon, .1 age chum salmon) caught in the 2½- and 3¼-inch mesh nets and the number of older fish (.2 and .3 age sockeye salmon, .2 age and older chum salmon) caught in the 4½- and 5¼-inch mesh nets, was used to compare relative abundance of immature sockeye and chum salmon in the three fishing areas: longitudes 176°W, 167°W, and 158°W.

The distribution and relative abundance of sockeye and chum salmon from repetitive fishing south of Adak Island along long. 176°W to lat. 49°30′N are given in Tables 6 and 7. A tabulation of average catch per shackle by 10-day periods and distances offshore showed that the .1 age sockeye salmon were most abundant 31–45 miles offshore, although abundance continued high to a distance of 60 miles offshore. Abundance was at its peak July 1–10 and July 21–31: two separate waves of .1 age sockeye salmon evidently passed near Adak Island in the summer of 1966. The older (.2 and .3 age) sockeye salmon were most

Table 6. Average catch of immature .1 age and older sockeye salmon per shackle, by 10-day period and distance south of Adak Island, 1966 (— indicates no sampling).

Time period	Miles from Adak Island							Average
	0–15	16–30	31–45	46–60	61–75	76–90	Over 90	
.1 age sockeye salmon								
6/21–30	0	0	3.67	3.83	1.67	—	—	1.83
7/1–10	—	5.00	27.25	2.50	—	0.25	0.83	7.17
7/11–20	—	0.08	6.67	2.92	0.79	0.21	0.17	1.81
7/21–31	8.29	10.29	5.33	11.92	1.92	1.25	—	6.50
8/1–10	0.42	7.11	0.42	3.50	0.58	0.50	—	2.09
8/11–20	4.58	8.67	0.83	0.75	0	3.42	1.33	2.80
8/21–31	0.08	2.75	—	—	—	—	—	1.42
Average	2.67	4.84	7.36	4.24	0.99	1.13	0.78	
.2 and .3 age sockeye salmon								
6/21–30	0.06	0.06	2.50	2.38	1.56	—	—	1.31
7/1–10	—	0.13	3.81	1.00	—	0.75	0.69	1.28
7/11–20	—	0	0.94	0.69	0.75	0.75	0.31	0.57
7/21–31	1.31	1.72	1.66	2.63	1.44	1.25	—	1.67
8/1–10	0	0.94	1.13	0.94	0.06	1.44	—	0.75
8/11–20	0.31	0.56	0.63	0.94	0.25	4.81	0.73	1.18
8/21–31	0.06	0.38	—	—	—	—	—	0.22
Average	0.35	0.54	1.78	1.43	0.81	1.80	0.58	

Table 7. Average catch of immature .1 age and older chum salmon per shackle, by 10-day period and distance south of Adak Island, 1966 (— indicates no sampling).

Time period	Miles from Adak Island							Average
	0–15	16–30	31–45	46–60	61–75	76–90	Over 90	
.1 age chum salmon								
6/21–30	0	0	0.08	0.08	0.42	—	—	0.12
7/1–10	—	0.25	21.33	4.20	—	0.75	2.33	5.77
7/11–20	—	0	1.42	1.92	3.25	8.50	0.75	2.64
7/21–31	2.67	1.87	2.29	3.50	1.17	0.58	—	2.01
8/1–10	0.00	0.28	0.42	0.17	0.17	0.17	—	0.20
8/11–20	0.50	1.58	0.46	0.17	0.08	0.25	0.39	0.49
8/21–31	0.08	0.08	—	—	—	—	—	0.08
Average	0.65	0.58	4.33	1.67	1.02	2.05	1.16	
.2 age and older chum salmon								
6/21–30	0		3.06	0.94	0.56	—	—	0.91
7/1–10	—	0.06	0.75	1.07	—	0.94	0.50	0.66
7/11–20	—	0	0	0.25	0.57	1.40	0.31	0.41
7/21–31	0.50	0.19	0.65	0.63	0.63	1.88	—	0.75
8/1–10	0	0.10	0.13	0.06	0.13	0.31	—	0.12
8/11–20	2.56	1.00	0.60	0.44	0.06	1.08	0.59	0.90
8/21–31	0.13	0.06	—	—	—	—	—	0.10
Average	0.64	0.20	0.87	0.57	0.39	1.12	0.47	

abundant 31–90 miles offshore; catches were too small to demonstrate significant peaks. These older fish appeared to be about equally abundant throughout the season.

Catch data for chum salmon (Table 7) showed a single period of abundance, July 1–10, of .1 age immature fish 31–45 miles offshore. Neither by 10-day period nor by distance offshore, however, were peaks of abundance evident for older chum salmon.

South of Unalaska Island along long. 167°W

Table 8. Average catch of immature .1 age and older sockeye salmon per shackle, by 10-day period and latitude along long. 167°W, 1966 (—indicates no sampling).

Time period	Latitude North North of 52°30′	51°31′–52°30′	50°31′–51°30′	49°31′–50°30′	South of 49°30′	Average
			.1 age sockeye salmon			
7/11–20	0	4.07	1.90	0.93	0.43	1.47
7/21–31	0.14	6.02	1.82	0.47	1.14	1.92
8/1–10	0.21	4.46	6.23	2.63	—	3.38
8/11–20	0.29	1.61	5.68	2.88	0.97	2.29
8/21–31	3.43	2.00	1.75	5.14	—	3.08
9/1–10	—	—	—	2.36	2.75	2.56
Average	0.81	3.63	3.48	2.40	1.32	
			.2 and .3 age sockeye salmon			
7/11–20	0	1.31	0.75	0.25	0	0.46
7/21–31	0.06	4.31	0.63	0.51	0.38	1.18
8/1–10	0.19	4.04	2.94	1.42	—	2.15
8/11–20	0.19	1.28	3.07	3.10	0.21	1.57
8/21–31	0.19	0.81	1.63	2.25	—	1.61
9/1–10	—	—	—	2.38	1.13	1.76
Average	0.13	2.35	1.80	1.65	0.43	

Table 9. Average catch of immature .1 age and older chum salmon per shackle, by 10-day period and latitude along long. 167°W, 1966 (—indicates no sampling).

Time period	Latitude North North of 52°30′	51°31′–52°30′	50°31′–51°30′	49°31′–50°30′	South of 49°30′	Average
			.1 age chum salmon			
7/11–20	0	0.07	0.07	0.07	0	0.04
7/21–31	0	0.33	0.22	2.15	2.79	1.10
8/1–10	0.14	0.53	2.54	1.68	—	1.22
8/11–20	1.36	1.14	2.75	1.76	0.68	1.54
8/21–31	4.21	0.36	0.04	0.29	—	1.23
9/1–10	—	—	—	1.36	1.68	1.52
Average	1.14	0.49	1.12	1.22	1.29	
			.2 age and older chum salmon			
7/11–20	0.31	2.13	3.29	2.56	0	1.60
7/21–31	3.63	4.08	1.81	3.53	1.06	2.82
8/1–10	13.31	5.59	7.35	4.03	—	7.57
8/11–20	4.00	2.72	7.29	3.46	1.16	3.73
8/21–31	1.06	0.51	0.53	0.75	—	0.71
9/1–10	—	—	—	2.38	4.40	3.39
Average	4.46	3.01	4.05	2.79	1.66	

(Tables 8 and 9) .1 age sockeye salmon were about equally abundant from July 11-September 10; their peak abundance occurred between latitudes 50°30′N and 52°30′N. The older immature sockeye salmon were slightly more abundant late than early in the season, and were most abundant in the same area, between latitudes 50°30′ and 52°30′N, as were the .1 age immature fish.

Relatively few .1 age chum salmon (Table 9) were caught along long. 167°W; no period of peak abundance was evident during July 11—September 10. The young chum salmon appeared in similar relative abundance throughout the sampling area, except for the area between lat. 51°31′ and 52°30′N, where catches were uniformly low. The older chum salmon were much more abundant than the young; their

Table 10. Average catch of .1 age and older sockeye salmon per shackle, by 10-day period and latitude along long. 158°W, 1966 (—indicates no sampling).

Time period	Latitude North					Average
	North of 53°30′	52°31′–53°30′	51°31′–52°30′	50°31′–51°30′	49°30′–50°30′	
			.1 age sockeye salmon			
7/1–10	2.29	0.43	—	—	—	1.36
7/11–20	—	—	0.64	0.41	0.28	0.44
7/21–31	1.03	1.54	2.17	—	—	1.58
8/1–10	3.58	0.33	3.14	2.67	—	2.43
8/11–20	0.17	—	0.08	2.00	1.54	0.95
8/21–31	—	0.04	1.42	4.75	—	2.07
9/1–10	—	—	2.83	—	—	2.83
Average	1.77	0.59	2.06	2.46	0.91	
			.2 and .3 age sockeye salmon			
7/1–10	0.31	1.81	—	—	—	1.06
7/11–20	—	—	2.56	0.77	0.71	1.35
7/21–31	0.69	1.25	6.00	—	—	2.65
8/1–10	0.33	1.67	7.20	6.00	—	3.80
8/11–20	0.21	—	3.08	3.92	0.59	1.95
8/21–31	—	0.21	1.58	7.42	—	3.07
9/1–10	—	—	2.16	—	—	2.16
Average	0.39	1.24	3.76	5.47	0.65	

Table 11. Average catch of .1 age and older chum salmon per shackle, by 10-day period and latitude along long. 158°W, 1966 (—indicates no sampling).

Time period	Latitude North					Average
	North of 53°30′	52°31′–53°30′	51°31′–52°30′	50°31′–51°30′	49°30′–50°30′	
			.1 age chum salmon			
7/1–10	0	0	—	—	—	0
7/11–20	—	—	0	0.05	0	0.02
7/21–31	0.36	0.30	0	—	—	0.22
8/1–10	5.33	0.33	0.95	1.58	—	2.05
8/11–20	1.17	—	0.08	0.25	3.50	1.25
8/21–31	—	0.29	2.08	5.17	—	2.51
9/1–10	—	—	0.08	—	—	0.08
Average	1.72	0.31	0.53	1.96	1.75	
			.2 age and older chum salmon			
7/1–10	1.44	1.69	—	—	—	1.57
7/11–20	—	—	3.38	2.80	1.47	2.55
7/21–31	1.47	6.04	2.00	—	—	3.17
8/1–10	5.25	1.92	5.55	5.58	—	4.58
8/11–20	1.29	—	0.42	4.17	3.84	2.43
8/21–31	—	0.29	0.50	8.91	—	3.23
9/1–10	—	—	0.33	—	—	0.33
Average	2.36	2.49	2.03	5.37	2.66	

peak period of abundance was August 1–10. These older fish were in similar abundance throughout the sampling area, except for slightly lower catches south of 50°30′N.

Results of fishing in the eastern North Pacific Ocean along long. 158°W are shown in Tables 10 and 11. No pronounced peak in abundance of .1 age sockeye salmon occurred during July 1-September 10; these

TABLE 12. Average catch of immature sockeye and chum salmon per shackle for three areas of the North Pacific Ocean, July–September, 1966.

Area (long.)	Sockeye salmon .1 age	Sockeye salmon .2 and .3 age	Chum salmon .1 age	Chum salmon .2 age and older
176°22′W (MV *Paragon*)	3.51	1.07	1.68	0.60
167°W (RV *George B. Kelez*)	2.37	1.32	1.05	3.24
158°W (MV *St. Michael*)	1.57	2.42	1.08	2.92

fish did appear to be slightly more abundant during August 1–10, and September 1–10. The .1 age fish were taken throughout the sampling area; they were slightly more abundant between lat. 50°30′ and 51°30′ N. Older sockeye salmon were most abundant during August 1–10 and August 21–31, and from lat. 50°30′ to 52°30′N.

Age .1 chum salmon along long. 158°W (Table 11) were most abundant August 21–31. Although fishing effort varied between 10-day periods and areas,

TABLE 13. Gill net and purse seine catches during comparative fishing of the MV *Paragon* and MV *Storm*[1] south of Adak Island, 1966.

Date	Approximate distance offshore[2] (miles)	Vessel and fishing effort	Sockeye	Chum	Pink	Coho	Chinook	Steelhead	Total fish
June 26	14	*Paragon:* 28 shackles	1	0	0	0	0	0	1
	10	*Storm:* 2 hauls	37	451	32	0	1	0	521
July 9	44	*Paragon:* 28 shackles	441	307	17	1	0	0	766
	44	*Storm:* 2 hauls	83	40	1	2	0	0	126
July 10	59	*Paragon:* 28 shackles	52	75	9	2	1	1	140
	58	*Storm:* 2 hauls	10	110	3	0	0	0	123
July 11	73	*Paragon:* 24 shackles	27	79	10	3	0	1	120
	77	*Storm:* 1 haul	1	23	0	0	0	0	24
July 12	89	*Paragon:* 28 shackles	23	209	18	7	2	0	259
	89	*Storm:* 3 hauls	11	12	2	0	2	0	27
July 13	104	*Paragon:* 28 shackles	11	24	11	36	1	1	84
	102	*Storm:* 3 hauls	3	51	3	0	2	0	59
July 14	82	*Paragon:* 28 shackles	20	80	9	23	1	0	133
	86	*Storm:* 3 hauls	7	62	1	1	1	0	72
July 15	67	*Paragon:* 28 shackles	32	39	11	9	0	0	91
	67	*Storm:* 3 hauls	67	62	3	0	1	0	133
July 17	37	*Paragon:* 28 shackles	102	18	11	2	0	0	133
	25	*Storm:* 2 hauls	212	88	8	0	3	0	311
July 18	22	*Paragon:* 28 shackles	1	0	0	0	0	0	1
	21	*Storm:* 2 hauls	321	168	6	3	0	0	498
July 23	14	*Paragon:* 28 shackles	267	125	8	33	0	0	433
	13	*Storm:* 3 hauls	61	47	3	20	1	0	132
July 24	29	*Paragon:* 28 shackles	221	21	4	10	0	0	256
	15	*Storm:* 3 hauls	145	26	1	4	1	0	177
July 31	14	*Paragon:* 28 shackles	5	0	0	0	1	0	6
	11	*Storm:* 2 hauls	14	111	0	1	0	0	126
Aug. 3	44	*Paragon:* 28 shackles	26	7	0	1	1	0	35
	46	*Storm:* 1 haul	6	0	0	4	0	0	10
Aug. 4	29	*Paragon:* 28 shackles	4	0	0	0	0	0	4
	29	*Storm:* 1 haul	71	8	0	0	0	0	79
Total		*Paragon:* 416 shackles	1,233	984	108	127	7	3	2,462
		Storm: 33 hauls	1,049	1,259	63	35	12	0	2,418

[1] MV *Storm* data from Fisheries Research Institute, University of Washington.

[2] Distances are measured due south along long. 176°22′W. Distances for the MV *Storm* are computed for the first haul position of each day.

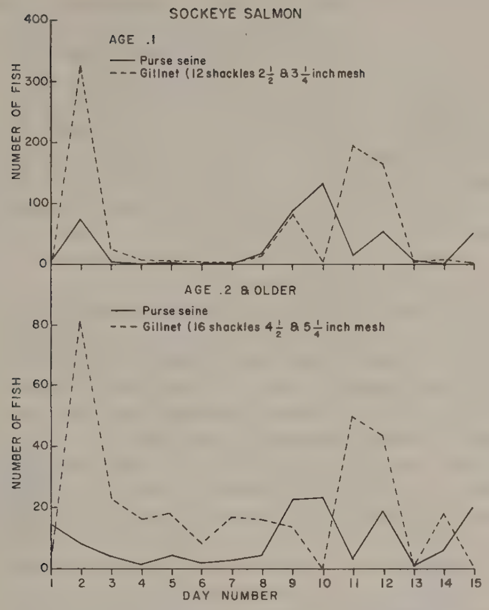

FIGURE 9. Comparison of catch per seine haul and catch in gill nets for sockeye salmon, south of Adak Island, June 26-August 4, 1966.

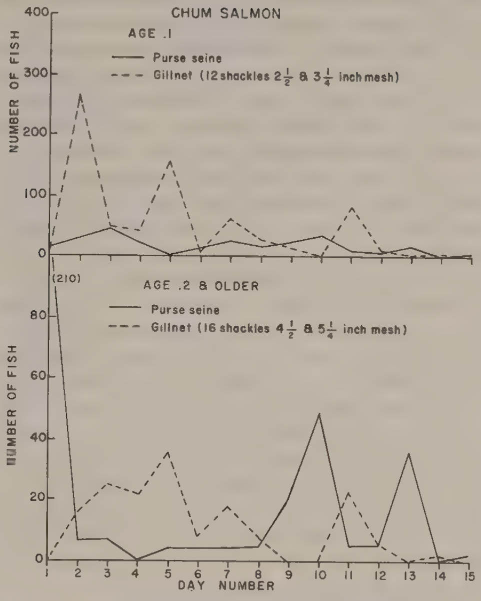

FIGURE 10. Comparison of catch per seine haul and catch in gill nets for chum salmon, south of Adak Island, June 26–August 4, 1966.

catches indicated that fish were most abundant at the northern and southern extremes of the sampling area. The older fish were most abundant August 1–10; unlike the young fish, they appeared in fair numbers during all sampling periods. The abundance was greatest between lat. 50°30′ and 51°30′N.

A comparison of average catches of immature sockeye and chum salmon per shackle from the three areas of fishing in the North Pacific Ocean (Table 12) indicates that .1 age sockeye salmon were most numerous along long. 176°W and least abundant in the eastern fishing area, along long. 158°W. On the other hand, .2 and .3 age sockeye salmon were least abundant near Adak Island, and most abundant along long. 158°W.

The variation in abundance of chum salmon was similar to that of sockeye salmon. The .1 age fish were most numerous near Adak Island and least abundant along long. 167°W and 158°W. The older chum salmon were in greatest abundance along long. 167°W and 158°W and least abundant along long. 176°W.

Salmon are typically present in the Adak Island area in the summer only north of lat. 49°N—a distance of approximately 160 miles south of the Aleutian Islands. In the eastern North Pacific, along long. 158°W, salmon are found mostly between the Alaska Peninsula and lat. 49°N, a distance of about 400 miles. Thus we would expect salmon to be more concentrated in the Adak Island area than in the eastern North Pacific. Area differences in peak abundance between age groups of both sockeye and chum salmon suggest the need for further research on migrations. Perhaps older fish do not migrate as far west—or the racial structures of the age groups may differ. Racial studies may clarify these problems.

COMPARISON OF PURSE SEINE AND GILL NET CATCHES

Comparative fishing was conducted with gill nets (MV *Paragon*) and purse seines (MV *Storm*) near Adak Island along long. 176°22′W. The purpose was to determine if purse seine and gill net catches, presumably from the same population of salmon, gave similar indications of the relative abundance.

A total of 15 sets was made by the vessels in approximately the same areas and 24-hour periods (Table 13). The relationship between catches of sockeye salmon in purse seines and gill nets (Figure 9) was not as close as that observed in 1963 (French, 1964). Catches of chum salmon (Figure 10) indicated little correlation between the two types of gear. The difficulty in comparing data from the two gear types is demonstrated by the following partial list of factors that most likely contribute to the poor correlation: (1) differences in the time of day (purse seine—daylight; gill net—darkness); (2) differences in the fishing time (purse seine—30 minutes, gill net—12 hours); (3) differences in physical size of gear (purse seine—20 fathoms deep with 250–300 fathom opening; gill net—4 fathoms deep and 1,200–2,000 fathoms long); and (4) differences in drift (gill nets may drift 2–20 miles, purse seines drift little while fishing).

Studies of Dropouts from Gill Nets

Percentages of salmon that drop out of gill nets were estimated from periodic inspection of the nets during normal fishing. Our experimental procedure was to patrol the nets at night from small boats (when sea conditions permitted), mark the locations of gilled salmon, and determine their presence or absence at later patrols and when gear was hauled in the morning. We used portable spotlights to observe salmon at night; reflected light made visible those fish in the upper portion of the net. The position of a salmon was marked by fastening a colored pin to the cork line directly over the fish.

The procedure is described below; some variation in timing occurred during various sets.

8: 00 p.m.: Put out 24–30 shackles of gill net.
9: 00 p.m.: First Patrol: Examine the nearest 7–14 shackles; mark the positions of gilled salmon with colored pins.
9: 30 p.m.: Second Patrol: Repeat the patrol and record the presence or absence of salmon at locations marked at the first patrol; mark locations of newly observed salmon with pins of a second color.
11: 30 p.m.: Third Patrol: Repeat the above procedure, again marking locations of newly observed salmon with pins of a third color.
8: 00 a.m.: Haul the gill net string; record presence or absence of salmon for all marked locations.

The gill net string was set and hauled 28 times. The study required the use of small boats from the research vessels at night; some patrols were not made in rough seas. There were 28 first patrols, 26 second patrols, and 20 third patrols completed during July and August from the three research vessels operating in the North Pacific Ocean.

We observed that dropout rates were substantial (35–55 percent) over a period of 6½–11½ hours (Table 14). The rates were about 4 percent when the gill nets were patrolled after ½–1 hour, and 21 percent after 2½ hours. Salmon known to be in the nets at least 2½ hours continued to drop out.

Sea lions were occasionally observed taking salmon from the nets. An example of suspected sea lion predation was documented when we marked 25 salmon between 10: 54 p.m. and 11: 20 p.m.; not a single salmon was present at the marked positions when nets were hauled at 7: 30 a.m. Sea lions were observed more frequently at inshore than at offshore stations, but it was impossible to observe just when or how frequently predation occurred. On six occasions, however, sea lions were near the nets the morning after salmon were marked. When these six sets were omitted from the analysis, the estimated dropout rates were reduced (Table 14). Omission of experiments in which sea lion predation was suspected usually reduced dropout rates, but estimated loss of salmon remained substantial.

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Table 14. Percentage loss of salmon from gill nets over varying periods of time.

Marking or patroling sequence and number of fish marked	Number of fish Possible[1]	Number of fish Observed	Time from marking (hours)	Percentage loss[2]
First marking-first patrol (92 fish)				
Second patrol	54	52	0.5–1.0	3.7 (2.1)
Third patrol	63	50	2.5	20.6 (17.9)
Haul of net	85	55	9.5–11.5	35.3 (29.5)
Second marking-second patrol (49 fish)				
Third patrol	38	30	1.5–2.0	21.1 (21.4)
Haul of net	47	21	8.0–11.0	55.3 (48.5)
Third marking-third patrol (161 fish)				
Haul of net	161	93	6.5–9.0	42.2 (21.9)

[1] The number "possible" usually differed from the number marked; some pins were lost and second and third patrols were not made in rough seas.

[2] Number in parentheses is percentage loss when certain sets were omitted from the analysis because of observed sea lion predation.

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OCEANOGRAPHY

by F. Favorite, W. B. McAlister, W. J. Ingraham, Jr., and D. Day

The ultimate goal of our oceanographic research is to predict marine conditions that affect salmon. During the past year, we maintained vigorous field programs and devoted most of our work toward determination of environmental factors that influence the distribution, migration, and abundance of Bristol Bay sockeye salmon.

On a fishery-oceanography cruise of the research vessel *George B. Kelez* during October and November 1965, large numbers of immature sockeye salmon were found south of the western Aleutian Islands between the Alaskan Stream and the Subarctic Current. On the assumption that this area has a large standing crop of planktonic populations, a seasonal biological sampling program was begun along long. 176°W from Adak Island to lat. 40°N. Data and materials were collected to measure productivity of plankton and to make a qualitative and quantitative estimate of food organisms in and adjacent to this area.

An oceanography cruise of the research vessel (*George B. Kelez*) during February, March, and April 1966, provided data which support the hypothesis that the Komandorskiy Ridge, south of the Aleutian-Komandorskiy island arc near long. 165° to 170°E, strongly influences the terminus of the Alaskan Stream. Because this is the area where Asian and Bristol Bay stocks of sockeye salmon are separated, future fishing there should be based upon knowledge of environmental factors, particularly currents.

During June, July, and August 1966 (RV *George B. Kelez*, MV *Paragon*, and MV *St. Michael*), oceanographic observations were made south of the Aleutian Islands to observe the relationships between the environment and immature sockeye salmon believed to

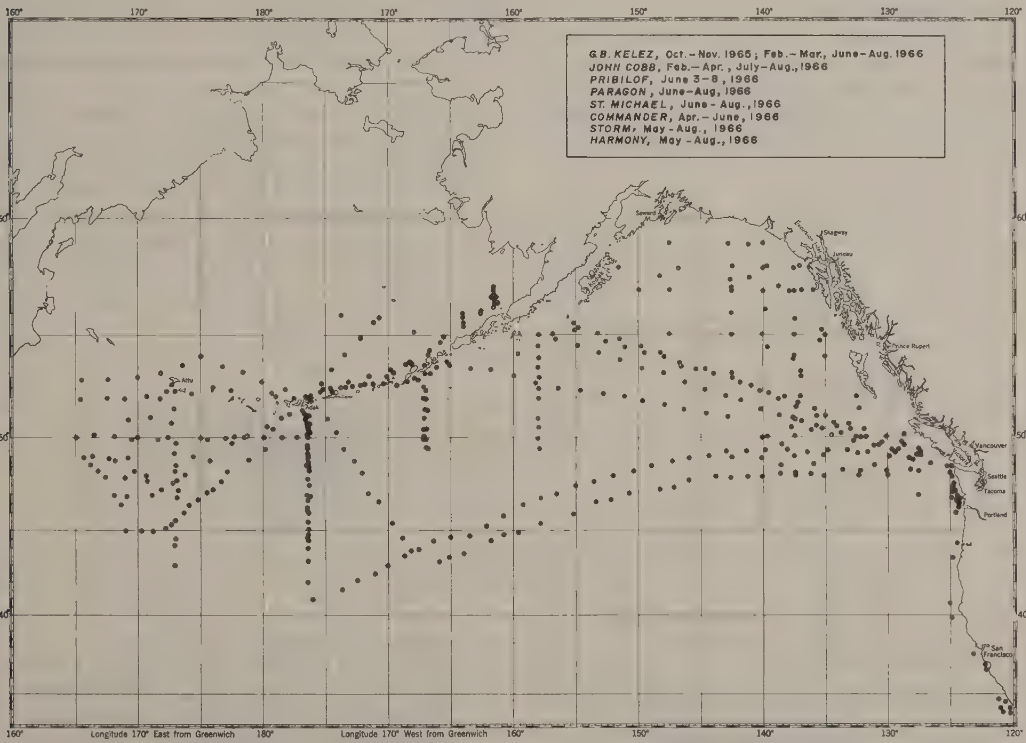

160°
170°
180°
170°
160°
150°
140°
130°
120°
G.B. KELEZ, Oct.–Nov. 1965; Feb.–Mar., June–Aug. 1966
JOHN COBB, Feb.—Apr., July–Aug., 1966
PRIBILOF, June 3–8, 1966
PARAGON, June–Aug, 1966
ST. MICHAEL, June–Aug., 1966
COMMANDER, Apr.–June, 1966
STORM, May–Aug., 1966
HARMONY, May–Aug., 1966
60°
50°
40°
Attu
Adak
Seward
Skagway
Juneau
Prince Rupert
Vancouver
Seattle
Tacoma
Portland
San Francisco
Longitude 170° East from Greenwich
Longitude 170° West from Greenwich

Figure 11. Bathythermograph observations, October 1965 to August 1966.

be of Bristol Bay origin. Preliminary analyses indicate a distribution similar to that observed during the autumn of 1965.

Because synoptic oceanographic coverage throughout the Subarctic Region by vessel was not possible, we proposed the use of drifting telemetry buoys. Preliminary experiments on measurement of the temperature by quartz and platinum sensors were carried out. In addition, we have continued to investigate oceanic circulation as calculated from pressure distributions at sea level. These movements are called wind-stress transports; analyses of data for the Subarctic Region in 1950–59 have provided an indication of monthly, seasonal, and annual variations in circulation during periods of no direct observation. This method, which is independent of shipboard oceanographic observations, has given some insight into the reasons for the anomalous change in Alaskan Stream conditions which occurred between the October-November 1965 and February-April 1966 cruises (RV *George B. Kelez*) and existed as late as July 1966.

FIELD INVESTIGATIONS

Bathythermograph Program

The scope of field work during October 1965 to August 1966 is reflected in the numbers and locations of bathythermograph (BT) observations made by personnel aboard Bureau and chartered fishing vessels (RV's *George B. Kelez*, *Pribilof*, and *John N. Cobb;* MV's *Paragon*, *St. Michael*, *Storm*, *Harmony*, *Commander*) (Figure 11). This year, temperature data to 275 meters obtained from the BT traces were coded in a standard format and radioed immediately to Seattle. Excellent information concerning temperature distribution in the eastern North Pacific was reported, particularly during the spring of 1966. This reporting system will be used in the future; tracks of some of the vessels (en route from Seattle to the Aleutian area) may also be modified to obtain optimum coverage.

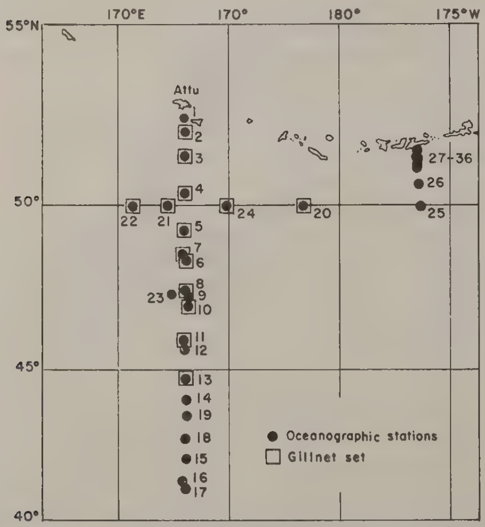


FIGURE 12. Oceanographic stations, October and November 1965, RV *George B. Kelez*.

Fishery-oceanography

We have known for a number of years that the abundance of immature sockeye salmon south of the Aleutian Islands reaches a maximum during July and August and decreases significantly thereafter. Estimates of relative abundance and age composition are one basis for forecasting Bristol Bay runs. Little is known, however, concerning either the location of these apparently westward moving salmon during autumn and early winter or environmental conditions south of the western Aleutian Islands. During October and November 1965 gill net sets and oceanographic observations were made in this area (Figure 12). When possible, fishing locations were selected on the basis of environmental conditions. No striking changes in the location or extent of known and previously described current systems and water masses were observed (Ingraham, MS 1966). Sockeye salmon were found in large numbers between the westward-flowing Alaskan Stream and eastward-flowing Subarctic Current (Figure 13). This area is characterized by low-velocity surface currents, a pronounced temperature-minimum stratum at depth (100–200 m), and evidence of a vertical divergence that could restore chemical nutrients to the surface. These conditions

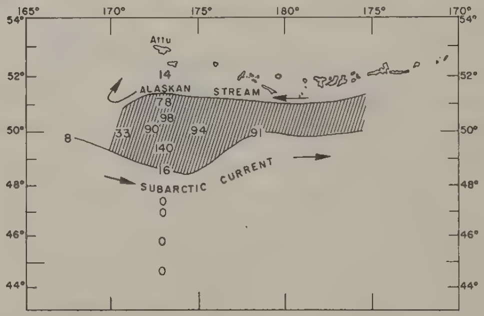


FIGURE 13. Distribution of sockeye salmon in relation to the location of the Alaskan Stream and Subarctic Current, October and November 1965. Numbers indicate salmon caught in gill nets; shaded area lies between the Alaskan Stream and Subarctic Current.

also occur in the central part of the Gulf of Alaska, where large numbers of sockeye salmon have been reported in previous years during the spring.

Closely spaced observations (5-mile intervals) south of Adak Island in November permitted the first reasonably precise indication of the geostrophic current structure across the Alaskan Stream. Velocities exceeding 40 cm/sec were obtained; this maximum flow occurred at 100-meters depth. The data also show that the 4°C isotherm is a good indicator of the main axis of the stream (Figure 14). In addition, the data pointed to the necessity for closely spaced oceanographic and fishing stations if we are to compare conditions and catches in this area from one month or year to the next.

Komandorskiy Ridge

Previous annual reports suggested that the western limit of Bristol Bay sockeye salmon migration south of the Aleutian Islands depends on the westward extent of the Alaskan Stream. It has been shown that during summer the westward flow in this current

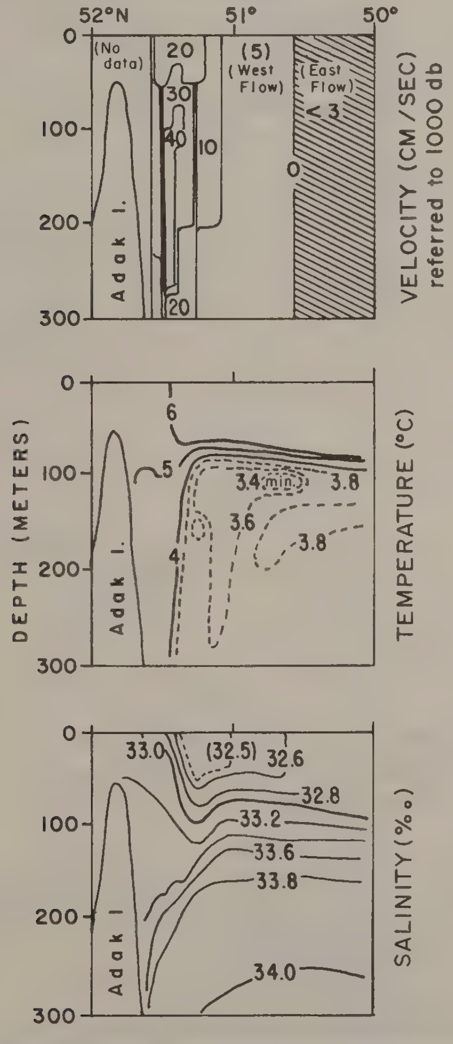


Figure 14. Vertical sections of velocity, temperature, and salinity south of Adak Island, November 1965.

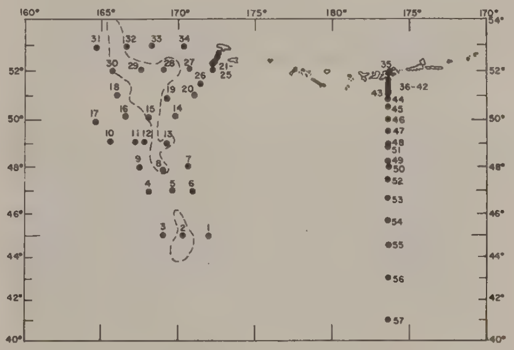


Figure 15. Oceanographic stations, February to March 1966, RV *George B. Kelez*. (Dashed line shows configuration of Komandorskiy Ridge.)

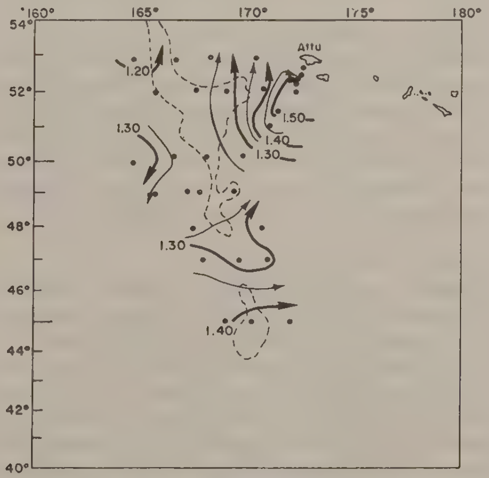


Figure 16. Geostrophic currents (referred to 1,500 db) showing discharge of Alaskan Stream into Bering Sea west of Attu Island. (Dashed line shows 4,000-m depth contour.)

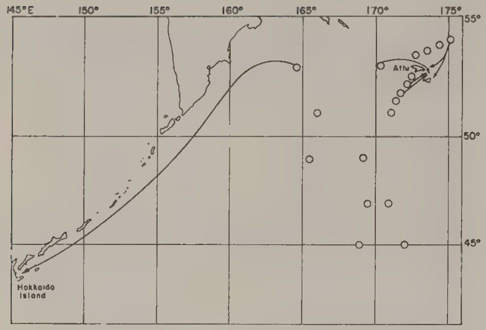


FIGURE 17. Release and recovery locations of drift bottles, March to July 1966 (open circles indicate release locations).

system terminates near long. 170°E (Favorite, 1967). Because a large number of immature sockeye salmon moved westward south of Adak Island during late summer and large numbers migrated along long. 171°E during autumn, it was considered necessary to locate the terminus of the Alaskan Stream during winter. Available hydrographic data suggested that the terminus might be determined by the position of the Komandorskiy Ridge. During March 1966 the research vessel *George B. Kelez* made extensive oceanographic observations, to depths of over 5,000 meters, along latitudinal transects of the Ridge from lat. 45°N to 53°N (Figure 15). These data showed no westward flow south of the Aleutian Islands west of Attu Island.

Geostrophic currents indicate an intense northward flow into the Bering Sea near long. 170°E (Figure 16). This indication has been confirmed by returns of drift bottles (Figure 17). Of particular interest is the return of a drift bottle recovered north of Hokkaido, which indicates an intense circulation during spring in the Western Subarctic Gyre. We hope that further recoveries will substantiate this discovery.

Alaskan Stream

Closely spaced oceanographic stations were occupied south of Adak Island to compare conditions in the Alaskan Stream during winter with those of the previous autumn. Although a westward flow was present (Figure 18), the warm water (>4°C)—normally found at depth (50–250 m) during all seasons at distances up to 100 miles south of Adak Island—was absent. This situation indicated a significant change in oceanographic conditions. The fact that the warm water was encountered south of the Alaska Peninsula in February 1966 while the *Kelez* was en route from Seattle to Adak Island implied that practically all of this warm water must have been recirculated in the Gulf of Alaska. This view was substantiated by subsequent bathythermograph observations during spring and summer (Figure 19).

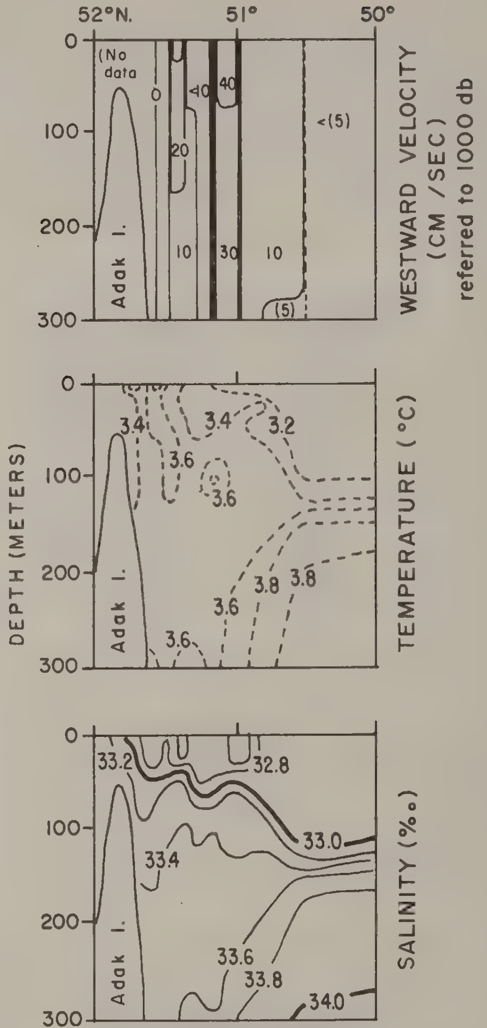


FIGURE 18. Vertical sections of velocity, temperature, and salinity south of Adak Island, March1966.

Biological Observations

In the autumn we observed concentrations of sockeye salmon between the two opposing current systems south of the Aleutian Islands to determine if

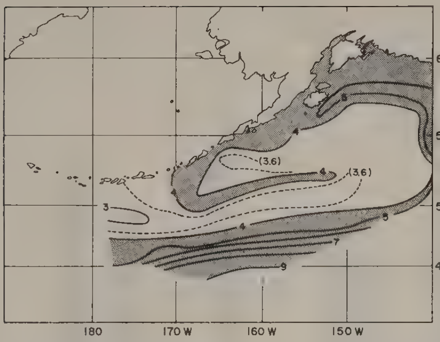

60N
55N
50N
45N
180
170 W
160 W
150 W
(3.6)
(3.6)
3
4
5
7
9

FIGURE 19. Distribution of mesothermal temperatures (°C), March to July 1966. Area with temperatures in excess of 4°C is shaded.

their presence could be ascribed to the availability of food organisms. We assessed and compared seasonal productivity and standing crops of macrozooplankton and nekton populations in known, discrete water masses of the Subarctic Region. In March 1966 we collected replicate samples after dark between the surface and 150-meters depth with a modified 3-foot Isaacs-Kidd midwater trawl along long. 176°25′W, from Adak Island to lat. 41°N.

Preliminary results (Figure 20) indicate that the biomass, expressed as wet-weight in grams per tow, was less than 10 grams immediately north and south of Adak Island and south of the Subarctic Region near lat. 41°N. Highest values, 24.3 and 24.2 grams, were in the Transition Zone between lat. 46°N and 47°N. Euphausiids were dominant (50 percent or more by number) or shared dominance with copepods in all zones in the Subarctic Region. These forms were scarce south of the Subarctic-Subtropic Boundary. No salps were found north of the boundary. Euphausiids were identified to determine if species distribution could be correlated with water properties in specific zones (Figure 21). *Thysanoessa longipes* was the dominant species in coastal and Alaskan Stream zones; *Thysanoessa inermis* was abundant only near Adak Island. *Euphausia pacifica* was dominant in samples for all zones except the Oyashio Extension, where it shared dominance with *Thysanoessa longipes; Nematoscelis difficilis* was found only south of the Subarctic-Subtropic Boundary.

It is too early to assess the significance of these studies. Plankton organisms caught by this net were not abundant where immature salmon were concentrated during autumn (Ridge Zone); their scarcity near Adak Island suggests that it is not a particularly good "feeding ground" during this period. These observations will be repeated once each season for a year and then evaluated to see if they should be continued.

PREDICTION OF ENVIRONMENTAL CONDITIONS

Although the exact mechanism is imperfectly known, it now appears evident that the direction and magnitude of major ocean currents are directly related to

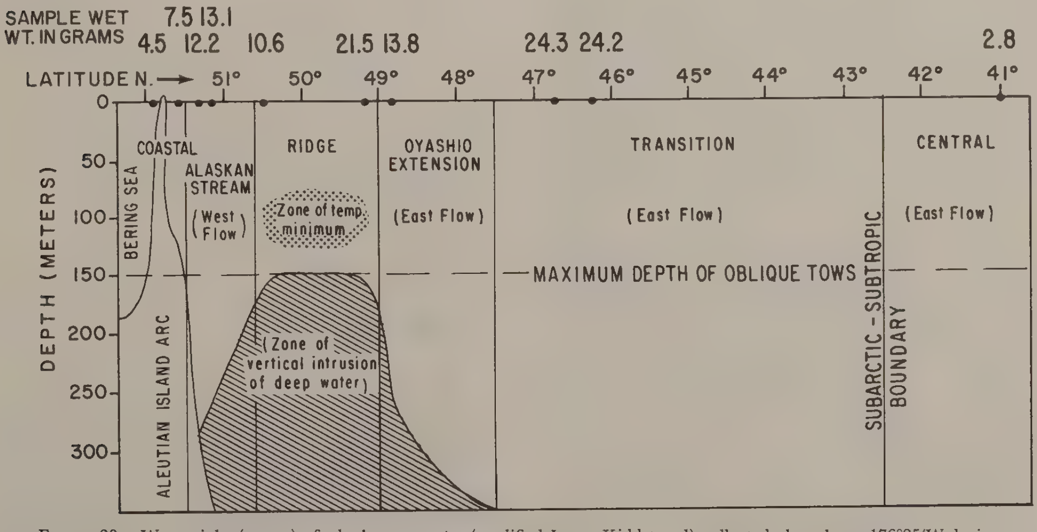
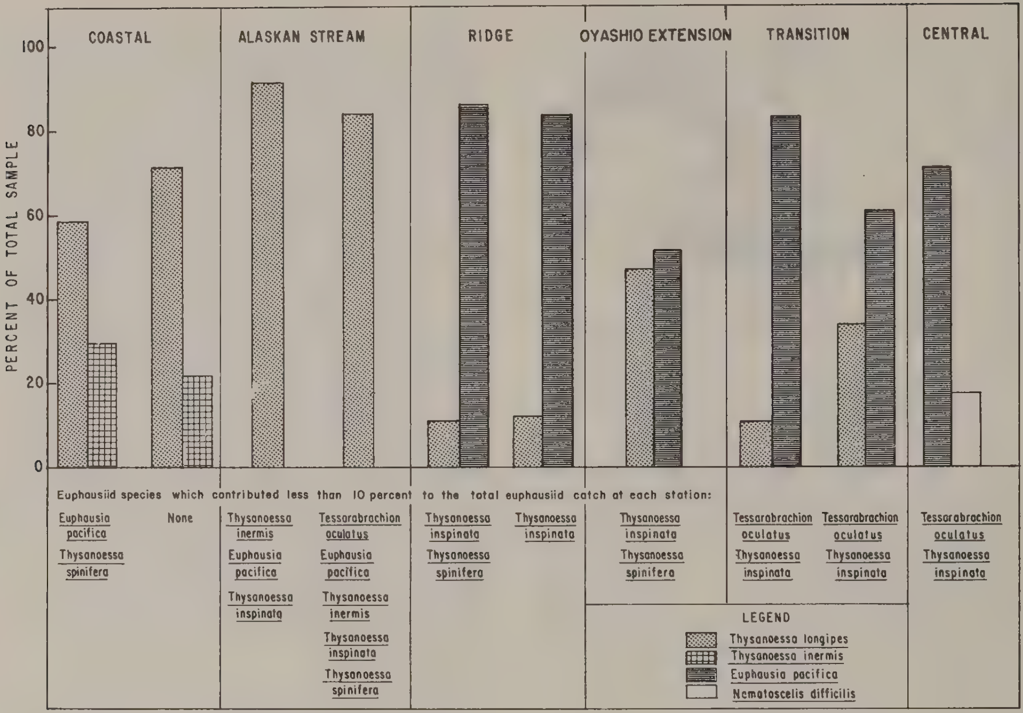

SAMPLE WET WT. IN GRAMS
7.5 13.1
4.5 12.2 10.6 21.5 13.8 24.3 24.2 2.8
LATITUDE N. →
51°
50°
49°
48°
47°
46°
45°
44°
43°
42°
41°
DEPTH (METERS)
0
50
100
150
200
250
300
COASTAL
BERING SEA
ALASKAN STREAM
(West Flow)
ALEUTIAN ISLAND ARC
RIDGE
Zone of temp. minimum
(Zone of vertical intrusion of deep water)
OYASHIO EXTENSION
(East Flow)
TRANSITION
(East Flow)
MAXIMUM DEPTH OF OBLIQUE TOWS
SUBARCTIC - SUBTROPIC BOUNDARY
CENTRAL
(East Flow)

FIGURE 20. Wet-weight (grams) of plankton samples (modified Isaacs-Kidd trawl) collected along long. 176°25′W during March 1966 in relation to specific zones in the Subarctic Region.



Euphausiid species which contributed less than 10 percent to the total euphausiid catch at each station:

Coastal	Coastal	Alaskan Stream	Alaskan Stream	Ridge	Ridge	Oyashio Extension	Transition	Transition	Central
Euphausia pacifica Thysanoessa spinifera	None	Thysanoessa inermis Euphausia pacifica Thysanoessa inspinata	Tessarabrachion oculatus Euphausia pacifica Thysanoessa inermis Thysanoessa inspinata Thysanoessa spinifera	Thysanoessa inspinata Thysanoessa spinifera	Thysanoessa inspinata	Thysanoessa inspinata Thysanoessa spinifera	Tessarabrachion oculatus Thysanoessa inspinata	Tessarabrachion oculatus Thysanoessa inspinata	Tessarabrachion oculatus Thysanoessa inspinata

FIGURE 21. Histogram of euphausiid species constituting more than 10% of total numbers of euphausiids at each station, and a tabulation of species which contributed less than 10% in relation to water mass.

wind stress. Using wind stress and transport charts (Fofonoff and Dobson, 1963) and imposing several realistic boundary conditions, we obtained an indication of average conditions by month, sesaon, and year. The mean transport for the 10-year period 1950–59 (Figure 22) corresponds to our conception of flow in the Subarctic Region: the area of divergence along lat. 40°N (which, in the central part of the ocean, corresponds to the Subarctic-Subtropic Boundary), the recirculation in the Gulf of Alaska, the intense flow along the south side of the Aleutian Islands (the Alaskan Stream), the southward flow along the Kamchatka and Kuril Island coastlines. Average transports were computed for each month in the Gulf of Alaska and the Alaskan Stream. It is apparent that the Alaskan Stream is a sensitive indicator of fluctuations in circulation. Data for 1950–59 (Table 15) show a maximum flow during December. The eastward flow indicated during August suggests that the Alaskan Stream should vanish. Although we have no evidence that it completely disappears, a reduction of transport has been observed during the summer.

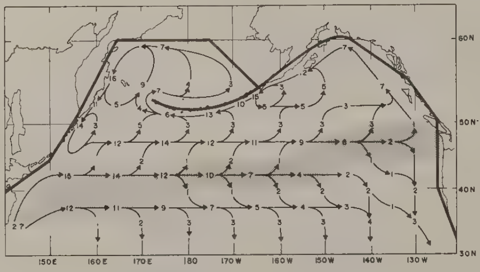


FIGURE 22. Mean integrated wind-stress transport ($\times 10^6$ m^3/sec), 1950 to 1959. Stippled area shows region of north-south divergence.

Monthly transports have been combined into seasonal charts. Those for winter and summer are the most informative. As might be expected because of light winds during summer, the transports are low (Figure 23). The area of divergence extends northeastward from Japan and occurs in the Gulf of Alaska between lat. 50° and 55°N. Almost the entire westward transport (8×10^6 m^3/sec) along the south Alaska coast is

TABLE 15. Total integrated west-east transport ($\times 10^6$ m^3/sec) in the Alaskan Stream at long. 180°. Negative values indicate eastward transport.

	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1950–59
January	−16	15	13	24	16	61	16	−5	39	16	18
February	19	3	27	32	13	−17	12	−5	28	7	12
March	46	−2	36	33	−1	2	43	24	−4	38	22
April	21	20	21	15	−4	28	14	14	19	4	15
May	28	12	3	22	16	39	42	5	32	8	21
June	0	6	5	−4	25	−11	20	9	10	3	6
July	12	−2	2	4	6	16	4	6	7	6	6
August	2	−5	−8	−13	−3	−10	5	−2	8	−10	−4
September	−3	2	6	−12	−1	6	−2	14	4	20	3
October	36	12	26	41	46	17	27	9	23	11	25
November	2	23	35	58	35	25	17	38	7	36	28
December	17	2	72	68	21	8	23	35	30	62	34
Average	14	7	20	22	14	14	18	12	17	17	16

required by continuity to recirculate in the Gulf of Alaska. Westward flow south of the Aleutian Islands is supplied from the west, and a transport of 6×10^6 m^3/sec is indicated for the East Kamchatka Current.

Winter conditions are considerably different. The area of divergence has moved southward, expanding the size of the region (Figure 24). Transport in the Gulf of Alaska has tripled and the Alaskan Stream is pronounced. Northward transport is 29×10^6 m^3/sec near long. 170°E (13×10^6 m^3/sec from the Western Subarctic Gyre and 16×10^6 m^3/sec from the Alaskan Stream) which appears larger than might be expected. During the February-April cruise (RV *George B. Kelez*), however, we measured a northward geostrophic volume transport of 25×10^6 m^3/sec in this area.

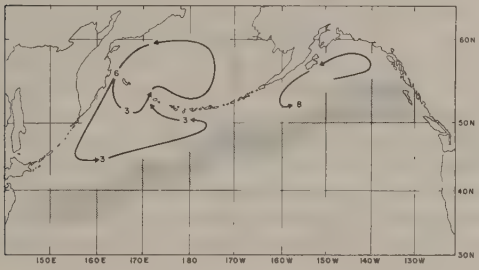


FIGURE 23. Mean integrated wind-stress transport ($\times 10^6$ m^3/sec), in summers of 1950 to 1959. Stippled area shows region of north-south divergence.

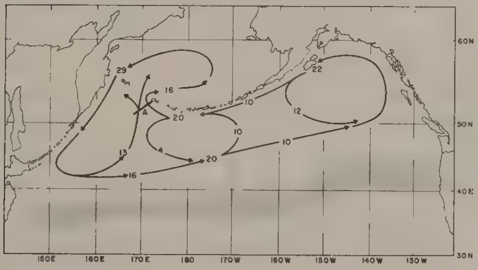


FIGURE 24. Mean integrated wind-stress transport ($\times 10^6$ m^3/sec) in January, February, March of 1950 to 1959. Stippled area shows area of north-south divergence. "A" indicates area where a geostrophic volume transport of 25×10^6 m^3/sec was obtained from oceanographic data collected during March 1966 (RV *George B. Kelez*).

This technique of using wind-stress measurements to measure flow in the ocean was used to investigate possible explanations for the absence of warm water from the Gulf of Alaska south of Adak Island during the winter and spring of 1966. This condition could be caused by a reduced northward component of flow in the Gulf of Alaska, or an increase in recirculation in the Gulf of Alaska, which would also cause a reduction in the flow of the Alaskan Stream. Sea-level pressure data for February 1966, from the U.S. Weather Bureau, were converted into wind-stress transports. Preliminary results (Figure 25) show that not only was the northward transport (10×10^6 m^3/sec)

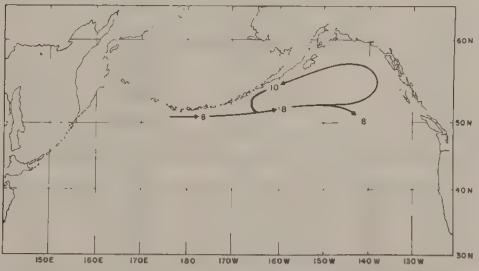


FIGURE 25. Integrated wind-stress transport ($\times 10^6$ m^3/sec), February 1966.

about half of the 10-year mean (22×10^6 m^3/sec), but that continuity required all of the westward flow south of the Alaska Peninsula to recirculate in the Gulf of Alaska. Thus, summer wind-stress conditions existed generally in the Gulf of Alaska during February 1966.

Although this examination of the anomalous conditions that existed in the eastern North Pacific during 1966 is only preliminary, it demonstrates the type of information that will be forthcoming from a forecasting program. Much remains to be done, but *in situ* data from telemetry buoys—correlated with changes in transports deduced from meteorological conditions—is a practical method that will permit useful forecasts of environmental conditions. If the change in flow south of Adak Island this year influenced the distribution of sockeye salmon in the western Subarctic Region, it is obvious that we must have knowledge of conditions throughout the entire Region. This requirement holds true if the forecasts are to be accurate, as changes in environmental conditions at either side of the Pacific Ocean can, in a short time, influence environmental conditions at the other side.

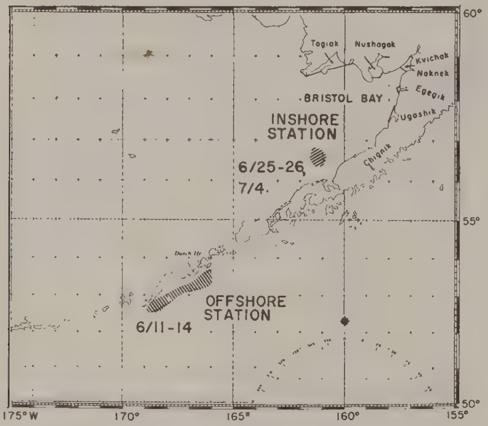


FIGURE 26. General sampling locations and dates for studies of ocean growth and mortality, 1966.

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OCEAN GROWTH AND MORTALITY

by T. A. Dark, K. N. Thorson, and G. K. Tanonaka

Since the establishment of the Japanese high seas salmon fishery a need has existed to understand the effects of high seas exploitation on biological yield. Lander *et al.* (1967) reviewed the related problems of natural mortality and growth, and reported on the 1965 studies. To test the assumption that maturing Bristol Bay sockeye salmon captured in offshore waters

TABLE 16. Summary of longline catches by the research vessel *George B. Kelez*, June 3-July 11, 1966.

Date	Set no.	Position		Number of shackles	Set time	Catch of salmon				
		Lat. N	Long. W			Sockeye	Chum	Pink	Unknown	Total
				Offshore						
6/11	1	53°35′	166°00′	20	0245	7	9	0	0	16
6/11	2	53°20′	166°58′	10	1517	2	3	0	0	5
6/12	3	52°59′	167°35′	20	0330	39	8	0	2	49
6/13	4	52°52′	168°30′	20	0330	48	17	5	1	71
6/13	5	52°37′	169°14′	10	1700	16	3	3	0	22
6/14	6	52°36′	169°14′	10	0310	31	5	1	0	37
6/14	7	52°37′	169°14′	10	0730	21	0	1	0	22
	Subtotal					*164*	*45*	*10*	*3*	*222*
				Inshore						
6/25	8	56°59′	161°30′	10	1000	10	1	1	0	12
6/26	9	56°41′	161°24′	10	0300	111	10	1	0	122
7/4	10	56°10′	161°24′	10	0305	1	0	0	0	1
	Subtotal					*122*	*11*	*2*	*0*	*135*
	Total					*286*	*56*	*12*	*3*	*357*

Table 17. Summary of sample sizes by treatment[1], sex, and area of capture, 1966 mortality studies.

	Group 1		Group 2		Group 3		
Sex	*M*	*F*	*M*	*F*	*Lot* 1	*Lot* 2	*Lot* 3
Offshore	29	26	21	21	25	14	—
Inshore	14	13	35	33	—	—	25
Total	43	39	56	54	25	14	25

[1] See text.

suffer the same tagging mortality as those captured later in inshore waters, research on the physiology of stress began in 1965 and was continued in 1966.

Mortality Studies

Areas and dates of sampling are shown in Figure 26; areas are the same as those designated in 1965 as " offshore " and " inshore ". Catches by area, date, and species are in Table 16. Longline gear was fished as in 1964 (Lander *et al.*, 1966).

At capture, sockeye salmon were sorted into three groups as shown in Table 17; Group 1 individuals were sampled immediately for blood and muscle tissue to assess the physiological effects of capture. Sockeye salmon sampled for blood were then tagged and placed in live tanks for further blood sampling (2–4 times per fish at 1–3 hour intervals). The first sample from each fish was taken from the heart with a syringe; later samples were from the ventral aorta posterior to the last gill arch. Muscle samples were taken from between the dorsal fin and the lateral line. Blood and muscle samples are being analyzed to determine lactate, calcium, sodium, and potassium levels as possible indices of physiological stress. Blood samples will also be analyzed for steroid hormones associated with maturation. Group 2 individuals were tagged and placed in live tanks for later sampling of blood and muscle to assess the effects of 2–6 hour rest periods. Group 3 individuals were tagged and held in live tanks to supplement physiological findings with observations on mortality.

Table 18. Distribution of mortality of sockeye salmon held in shipboard live tanks, 1966 mortality studies.

	Number of deaths		
Days after capture	Lot 1 (25 fish)	Lot 2 (14 fish)	Lot 3 (25 fish)
1	—	—	—
2	Experiment terminated	—	—
3		—	4
4		1	8
5		—	2
6		—	—
7		—	10
8		—	—
9		1	1
10		1	—
11		—	—
12		3	—
13		—	—
14		—	—
15		—	—
16		2	—
17		2	—
18		—	—
19		—	—
20		1	—
21		—	—
22		—	—
23		—	—
24		2	—
25		—	—
26		1 released alive	—
Total	0	14	25

Few salmon were available for the holding studies (Group 3). Early in the cruise, three sockeye salmon were held for 48 hours, eight for 24 hours, and 14 for 3 hours—until the pumps supplying water to the tanks were shut off inadvertently. None of these 25 fish died (Lot 1). On June 13, 14 fish (Lot 2) were put in the tanks just before the vessel left the offshore station (see Figure 26). On June 26 at the inshore station (see Figure 26), 25 more fish (Lot 3) were held for observation.

The times of mortality in each lot appear in Table 18. The results of the holding studies are presently difficult to interpret in terms of possible differences between offshore and inshore samples. Sample sizes were small, and physical and chemical properties in the holding tanks may have changed. Weather was more severe in Bristol Bay where the increased turbulence may have placed added stress on fish in the tanks. Those fish of Lot 2 that survived until the vessel reached Bristol Bay, and all fish of Lot 3, soon developed fungus infections on body and fins. This infection may have contributed to the earlier average time of mortality in Lot 3.

Final evaluation of the holding studies, however, must await analysis of blood and tissue samples.

Growth Studies

One objective of the 1965 tagging studies (Lander *et al.*, 1967) was to estimate the growth of Bristol Bay sockeye salmon in the last 30 days of their ocean life.

Changes in body length by time intervals between release and recovery showed a wide range of positive and negative values. We attributed this variation to (1) different measurement techniques used at times of release and recovery, and (2) measurement of fish at recovery in different physical states (fresh, frozen, thawed), all of which affect the actual length of the fish (Parker, 1963). Lack of control over quality of data prevented a valid estimate of short-term ocean growth.

Field studies in 1966 were designed to examine these sources of variation. The objectives were to determine: (1) variability of body weights taken at sea, (2) changes in length attributable to sexual dimorphism, and (3) changes in length and weight resulting from freezing and thawing. These objectives were not met because the vessel was diverted to index the 1966 return of sockeye salmon to Bristol Bay.

SUMMARY

A tagging study in 1965 was designed to estimate natural mortality of maturing Bristol Bay sockeye salmon during their last month at sea. At the same time, a study was conducted to assess physiological stress caused by capture and tagging. The latter study was continued in 1966.

Samples of blood and muscle tissue were collected from sockeye salmon taken from an area just south of Unalaska Island and later from Bristol Bay. These samples are being analyzed to determine lactate, calcium, sodium, and potassium levels as possible indices of stress.

This study was supplemented by observation of survival of fish held in shipboard live tanks. Small sample sizes and possible changes in water properties in the tanks made interpretation of the results difficult. Conclusions must await analysis of blood and muscle samples.

Objectives of the studies on growth were not satisfied because the vessel was diverted to Bristol Bay to index the incoming return.

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STUDIES ON MATURITY OF SOCKEYE SALMON

by Warren E. Ames

The ability to determine the stage of maturation of salmon at sea and to forecast their year of spawning is important in the study of their marine life history. Gonad weight is an adequate index of salmon maturity, but is reliable only two or three months before spawning. Biochemical changes associated with maturity may be serologically detected, however, several months before gross gonadal changes appear.

The onset of maturity in female salmon is accompanied by the appearance of vitellin in the blood serum. The vitellin is a phospholipoprotein presumably synthesized in the liver under hormonal control, transported by the circulatory system to the ova, and concentrated there as yolk material. Work was undertaken this year to find if vitellin substance could be detected at the site of production in the liver. If so, the onset of maturity might be detected as early as six months to one year before spawning.

METHODS AND RESULTS

In these preliminary studies, vitellin production was stimulated in immature sockeye salmon under controlled laboratory conditions by intramuscular injections of estrone. Three procedures were used to detect and measure vitellin in the livers, ovaries, and sera of injected and control groups: (1) the double diffusion precipitation test of Ouchterlony (Ridgway, Klontz, and Matsumoto, 1962); (2) a single diffusion quantitative precipitin test similar to that of Fahey and McKelvey (1965); and (3) acrylamide gel electrophoresis.

The three methods of analysis consistently gave the same results. Vitellin was detected in the serum three

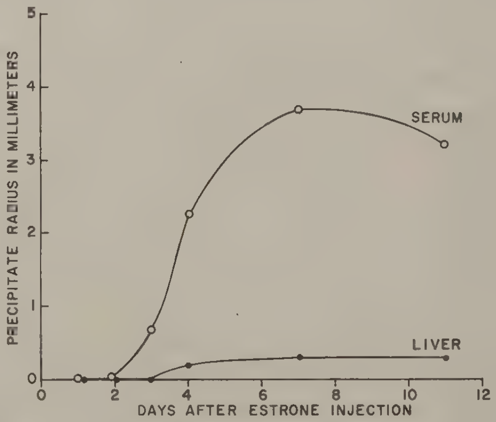

FIGURE 27. Concentration of vitellin in the blood sera and livers of immature sockeye salmon after estrone injection. Relative quantities were determined by single diffusion quantitative precipitation tests; each point represents an average of 10 samples.

days after estrone injection, but liver vitellin was not apparent until the fourth day. The quantity of serum vitellin increased with each sample interval through three to seven days, but liver vitellin remained at a constantly low level even after its initial appearance (Figure 27).

Vitellin was not detected in the ovaries of stimulated immature salmon, presumably because the ovaries were immature; if they had reached a sufficiently advanced stage of maturation by natural or pituitary hormone induction, they would have been capable of storing vitellin.

The consistent finding that vitellin was detectable, by the tests used, in the serum earlier than in the liver indicates that if vitellin is to be detected sooner in the liver, more sensitive tests must be used. Two such methods are presently being studied: passive hemagglutination and fluorescent antibody tests.

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SCALE STUDIES OF SOCKEYE SALMON

by James E. Mason

This report contains the result of classifying to continent of origin the samples of immature sockeye salmon collected in 1962 and 1963 by the vessels *George B. Kelez*, *Bertha Ann*, and *Commander*. Procedures were the same as described in the 1965 report (Mason, 1967), except that length criteria for maturity (Hartt, 1962) were applied to samples from the vessel *Commander*. Also mentioned is a preliminary study of the heights of circuli on sockeye salmon scales.

CLASSIFICATION OF IMMATURE SOCKEYE SALMON

Samples of mature sockeye salmon collected in 1964 aboard Japanese motherships during June 15–19 near lat. 50°N and long. 165°-168°E were used as Asian standards for classifying immature fish collected in 1963 (Table 19). Samples of immature fish collected in 1962 and 1963 are listed in Tables 20 and 21, respectively. Only those with more than 17 fish were classified to continent of origin. The two ocean ages (.1 and .2) were classified separately for the present report.

Immature sockeye salmon caught by the three United States vessels in the spring and summer of 1963 had the following age composition: 1.1—40.3%, 1.2—27.1%, 2.1—21.4%, 1.3—0.5%, 2.2—8.4%, 3.1—1.2%, 3.2—0.4%, all others—0.7%. These groups, a year older, made up 91 percent of the Bristol Bay return in 1964 (Alaska Department of Fish and Game, 1964). The immature fish in 1963 were, therefore, classified by the error of misclassification, 20.7713 percent, for Bristol Bay in 1964 (Mason, 1967). Along with reference samples of presumably Asian matures, Table 19 gives the other error of misclassification, 27.3381 percent, for 1964. The corrected percentages of Bristol Bay type sockeye salmon in the 85 samples that contained more than 17 immature .1 and .2 age sockeye salmon in 1962, and the 105 samples in 1963, are listed in Tables 20 and 21, respectively.

TABLE 19. Classification of selected samples of mature sockeye salmon for use as standards of Asian type, 1964.

Name of vessel	Sample date	Lat. N	Long. E	Sample size	Number of Bristol Bay type
Meisei Maru	6/16	50°47′	166°59′	20	4
Otsu Maru	6/15	49°37′	164°40′	24	6
,, ,,	6/16	49°46′	165°22′	23	7
,, ,,	6/17	50°13′	165°30′	20	5
,, ,,	6/18	49°58′	165°26′	13	5
,, ,,	6/19	49°04′	165°23′	24	7
Kyokuzan Maru	6/15	51°36′	168°19′	20	9
Kizan Maru	6/15	49°32′	166°14′	21	4
,, ,,	6/16	49°35′	165°57′	23	6
,, ,,	6/17	49°31′	165°58′	22	5
,, ,,	6/18	49°30′	165°49′	16	3
,, ,,	6/19	49°39′	166°03′	20	8
Takoshima Maru	6/19	48°57′	166°15′	14	4
Meiyo Maru	6/19	48°01′	167°17′	18	3
Total				278	76
Percent					27.33

TABLE 20. Samples with more than 17 immature sockeye salmon collected in the spring and summer of 1962 aboard the research vessels *Commander*, *Bertha Ann*, and *George B. Kelez.*

Vessel and sample number	Set number	Date	Lat. N.	Long.	Sample size	Number of Bristol Bay type	Percentage classified: Bristol Bay type	Percentage classified: Kamchatkan type	Corrected percentage Bristol Bay type	90 percent confidence interval
COMMANDER					*.1 age sockeye salmon*					
1	14	6/22	51°25′	176°30′W	22	11	50.00	50.00	42	7–76
2	16	6/23	51°30′	176°30′W	55	34	61.18	38.82	63	42–84
3	18	6/23	51°32′	176°38′W	30	13	43.33	56.67	29	0–58
4	23	6/30	51°29′	176°30′W	48	27	56.25	43.75	54	31–77
5	27	7/3	51°34′	176°39′W	21	17	80.95	19.05	100	74–100
6	42	7/15	51°19′	176°25′W	24	15	62.50	37.50	66	34–98
7	44	7/15	51°21′	176°24′W	21	11	52.38	47.62	46	11–81
8	47	7/20	51°24′	176°29′W	44	32	72.73	27.27	86	64–100
9	48	7/20	51°16′	176°24′W	70	52	74.28	25.72	89	72–100
10	53	7/22	51°20′	176°31′W	40	32	80.00	20.00	100	80–100
11	55	8/8	51°26′	176°30′W	116	78	67.24	32.76	75	61–89
12	56	8/8	51°26′	176°30′W	46	32	69.56	30.44	80	58–100
					.2 age sockeye salmon					
13	19	6/24	51°09′	176°30′W	23	18	78.26	21.74	97	69–100
14	20	6/24	51°01′	176°31′W	43	34	79.07	20.93	98	78–100
15	45	7/15	51°21′	176°24′W	24	20	83.33	16.67	100	82–100
16	47	7/20	51°24′	176°29′W	24	22	91.66	8.34	100	*
17	48	7/20	51°16′	176°24′W	35	29	82.86	17.14	100	85–100
18	53	7/22	51°20′	176°31′W	40	27	67.50	32.50	76	52–99
BERTHA ANN					*.1 age sockeye salmon*					
19	21	7/12	52°52′	167°07′W	82	67	81.71	18.29	100	90–100
20	22	7/14	51°50′	167°00′W	85	63	74.12	25.88	88	73–100
21	23	7/15	52°20′	166°58′W	35	23	65.71	34.29	72	46–98
22	24	7/17	51°00′	170°52′W	21	19	90.48	9.52	100	*
23	25	7/18	51°28′	170°58′W	51	32	62.74	37.26	59	37–81
24	26	7/19	51°56′	171°00′W	31	29	93.55	6.45	100	*
25	27	7/21	51°30′	173°55′W	51	43	84.31	15.69	100	92–100
26	28	7/22	51°00′	173°54′W	49	38	77.55	22.45	95	76–100
27	29	7/23	50°29′	173°56′W	39	26	66.67	33.33	74	50–98
28	30	7/24	51°04′	174°02′W	89	65	73.03	26.97	86	71–100
29	31	7/25	51°33′	174°04′W	68	45	66.18	33.82	73	55–91
30	32	7/31	51°14′	176°34′W	39	32	82.05	17.95	100	84–100
31	33	8/4	50°50′	179°00′E	22	11	50.00	50.00	42	7–76
32	34	8/8	50°19′	178°59′E	45	30	66.67	33.33	74	52–96
33	35	8/9	51°12′	176°00′E	59	34	57.63	42.37	77	57–96
34	36	8/10	50°41′	175°54′E	19	12	63.16	36.84	67	32–100
35	37	8/11	51°57′	172°50′E	53	47	88.68	11.32	100	*
36	38	8/13	51°23′	172°53′E	74	58	78.38	21.62	97	82–100
37	39	8/14	50°53′	173°00′E	59	51	86.44	13.56	100	98–100
38	44	8/27	52°02′	157°04′W	22	3	13.64	86.36	0	*
39	45	8/28	52°45′	157°00′W	18	0	00.00	00.00	0	*
					.2 age sockeye salmon					
40	9	6/11	50°57′	176°00′W	18	12	66.67	33.33	74	38–100
41	14	6/25	51°10′	170°41′E	24	17	70.83	29.17	82	52–100
42	15	6/26	50°58′	170°05′E	18	12	66.67	33.33	74	38–100
43	17	6/28	50°53′	171°11′E	48	18	37.50	62.50	17	0–40
44	20	7/2	51°00′	177°00′W	88	67	76.14	23.86	92	78–100
45	21	7/12	52°52′	167°07′W	191	149	78.01	21.99	96	86–100
46	22	7/14	51°50′	167°00′W	125	75	60.00	40.00	61	47–75
47	23	7/15	52°20′	166°58′W	22	12	54.54	45.46	50	16–84

TABLE 20. Continued.

Vessel and sample number	Set number	Date	Lat. N	Long.	Sample size	Number of Bristol Bay type	Percentage classified Bristol Bay type	Percentage classified Kamchatkan type	Corrected percentage Bristol Bay type	90 percent confidence interval
48	24	7/17	51°00′	170°52′W	36	19	52.78	47.22	47	20–74
49	25	7/18	51°28′	170°58′W	106	56	52.83	47.17	47	32–63
50	26	7/19	51°56′	171°00′W	126	108	85.71	14.29	100	*
51	27	7/21	51°30′	173°55′W	53	44	83.02	16.98	100	*
52	28	7/22	51°00′	173°54′W	29	19	65.52	34.48	72	44–100
53	29	7/23	50°29′	173°56′W	53	30	56.60	43.40	54	33–76
54	30	7/24	51°04′	174°02′W	180	127	70.56	29.44	82	71–92
55	31	7/25	51°33′	174°04′W	24	15	62.50	37.50	66	34–98
56	32	7/31	51°14′	176°34′W	32	27	84.38	15.62	100	*
57	34	8/8	50°19′	178°59′W	91	48	52.75	47.25	47	30–64
58	35	8/9	51°12′	176°00′E	206	151	73.30	26.70	87	77–97
59	36	8/10	50°41′	175°54′E	89	58	65.17	34.83	71	55–87
60	37	8/11	51°57′	172°50′E	154	131	85.06	14.94	100	*
61	38	8/13	51°23′	172°53′E	159	113	71.07	28.93	83	71–94
62	39	8/14	50°53′	173°00′E	74	59	79.73	20.27	99	85–100
63	40	8/15	52°21′	170°00′E	31	21	67.74	32.26	76	49–100
64	41	8/18	53°00′	166°00′E	47	19	40.42	59.58	23	0–45
65	44	8/27	52°02′	157°04′W	52	14	26.92	73.08	0	0–16
66	45	8/28	52°45′	157°00′W	31	9	29.03	70.97	1	0–27
67	46	8/29	53°30′	157°00′W	18	3	16.67	83.33	0	0–5
GEORGE B. KELEZ					*.1 age sockeye salmon*					
68	7	8/24	51°00′	154°00′W	21	3	14.28	85.72	0	*
69	10	8/27	52°02′	157°04′W	32	0	00.00	100.00	0	*
70	16	9/9	53°14′	159°58′W	80	13	16.25	83.75	0	*
71	17	9/10	52°30′	160°00′W	40	13	32.50	67.50	8	0–31
72	18	9/11	51°45′	160°01′W	33	5	15.15	84.85	0	*
73	21	9/16	51°45′	162°59′W	35	9	25.71	74.29	0	0–18
					.2 age sockeye salmon					
74	4	8/19	53°15′	154°03′W	26	6	23.08	76.92	0	0–16
75	6	8/22	51°45′	154°00′W	64	9	14.06	85.94	0	*
76	7	8/24	51°00′	154°00′W	47	12	25.53	74.47	0	0–14
77	10	8/27	52°02′	157°04′W	68	14	20.59	79.41	0	*
78	11	8/28	52°45′	157°00′W	29	9	31.03	68.97	5	0–32
79	12	8/29	53°35′	156°59′W	32	4	12.50	87.50	0	*
80	15	9/7	54°00′	160°00′W	30	10	33.33	66.67	9	0–37
81	16	9/9	53°14′	159°58′W	109	32	29.36	70.64	1	0–15
82	17	9/10	52°31′	160°00′W	68	23	33.82	66.18	10	0–28
83	18	9/11	51°45′	160°01′W	162	35	21.60	78.40	0	*
84	21	9/16	51°45′	162°59′W	114	29	25.44	74.56	0	0–7
85	22	9/17	52°30′	162°59′W	112	26	23.21	76.79	0	0–2

* Observed percentage is greater (or less) than expected from pure Bristol Bay (or Kamchatkan) type.

Table 21. Samples with more than 17 immature sockeye salmon collected in the spring and summer of 1963 aboard the research vessels *Commander*, *Bertha Ann*, and *George B. Kelez*.

Vessel and sample number	Set number	Date	Lat. N	Long. W	Sample size	Number of Bristol Bay type	Percentage classified		Corrected percentage Bristol Bay type	90 percent confidence interval
							Bristol Bay type	Kamchatkan type		
Commander					*.1 age sockeye salmon*					
1	15	6/6	51°13′	176°21′	30	13	43.33	56.67	31	2–60
2	19	6/15	51°18′	176°30′	30	13	43.33	56.67	31	2–60
3	20	6/15	51°00′	176°17′	52	24	46.15	53.85	36	14–58
4	43	7/10	51°20′	176°19′	59	27	45.76	54.24	36	15–56
5	44	7/10	51°20′	176°19′	41	24	58.54	41.46	60	36–85
6	47	7/17	51°18′	176°21′	77	65	84.42	15.58	100	97–100
7	48	7/19	51°33′	176°25′	33	24	72.73	27.27	87	63–100
8	51	7/27	51°26′	176°25′	181	146	80.66	19.34	100	93–100
9	52	7/28	51°35′	176°22′	38	31	81.58	18.42	100	85–100
10	54	7/28	51°38′	176°20′	59	50	84.74	15.26	100	96–100
11	55	8/4	51°37′	176°25′	64	55	85.94	14.06	100	99–100
12	56	8/5	51°34′	176°24′	85	76	89.41	10.59	100	*
13	57	8/5	51°34′	176°24′	36	28	77.78	22.22	97	75–100
14	58	8/5	51°34′	176°24′	53	43	81.13	18.87	100	87–100
15	65	8/13	53°22′	166°17′	49	31	63.26	36.74	69	47–91
					.2 age sockeye salmon					
16	19	6/15	51°18′	176°30′	25	19	76.00	24.00	94	67–100
17	20	6/15	51°00′	176°17′	18	15	83.33	16.67	100	80–100
18	47	7/17	51°18′	176°21′	25	19	76.00	24.00	94	67–100
19	51	7/27	51°26′	176°25′	24	17	70.83	29.17	84	54–100
Bertha Ann					*.1 age sockeye salmon*					
20	19	7/23	53°00′	162°00′	130	106	81.54	18.46	100	94–100
21	20	7/24	51°59′	162°04′	42	35	83.33	16.67	100	90–100
22	21	7/25	51°00′	162°00′	37	26	70.27	29.73	83	59–100
23	25	7/29	51°31′	162°02′	149	102	68.46	31.54	79	67–91
24	27	7/31	53°30′	162°00′	28	19	67.86	32.14	78	50–100
25	32	8/5	51°30′	162°00′	93	43	46.24	53.76	36	20–53
26	33	8/6	52°00′	162°00′	101	50	49.50	50.50	43	27–58
27	34	8/7	52°20′	162°00′	54	28	51.85	48.15	47	26–69
28	35	8/8	52°40′	162°00′	31	17	54.84	45.16	53	25–81
29	36	8/9	53°00′	162°00′	25	15	60.00	40.00	63	32–94
30	37	8/10	53°20′	162°00′	31	18	58.06	41.94	59	31–87
31	43	8/18	52°20′	162°00′	29	19	65.52	34.48	74	46–100
32	44	8/19	51°40′	162°00′	31	18	58.06	41.94	59	31–87
33	45	8/20	51°00′	162°00′	78	36	46.15	53.85	36	18–54
34	46	8/21	50°20′	162°00′	28	8	28.57	71.43	3	0–29
35	49	8/25	50°40′	162°00′	54	24	44.44	55.56	33	12–54
36	50	8/26	51°20′	162°00′	32	15	46.88	53.12	38	10–66
37	51	8/27	52°00′	162°00′	20	12	60.00	40.00	63	28–98
38	57	9/4	52°00′	162°00′	39	21	53.85	46.15	51	26–76
39	58	9/5	51°00′	162°00′	106	48	45.28	54.72	35	19–50
40	59	9/6	50°00′	162°00′	27	10	37.04	62.94	19	0–48
41	61	9/8	50°30′	162°00′	36	19	52.78	47.22	49	23–75
42	62	9/9	51°30′	162°00′	125	63	50.40	49.60	44	30–59
					.2 age sockeye salmon					
43	20	7/24	51°59′	162°04′	25	19	76.00	24.00	94	67–100
44	21	7/25	51°00′	162°00′	83	56	67.47	32.53	77	61–94
45	24	7/28	50°30′	162°00′	28	21	75.00	25.00	92	66–100
46	25	7/29	51°31′	162°02′	88	44	50.00	50.00	44	27–61

* Observed percentage is greater (or less) than expected from pure Bristol Bay (or Kamchatkan) type.

TABLE 21. Continued.

Vessel and sample number	Set number	Date	Lat. N	Long. W	Sample size	Number of Bristol Bay type	Percentage classified		Corrected percentage Bristol Bay type	90 percent confidence interval
							Bristol Bay type	Kamchatkan type		
47	32	8/5	51°30′	162°00′	42	19	45.24	54.76	34	10–59
48	33	8/6	52°00′	162°00′	48	23	47.92	52.08	40	17–63
49	34	8/7	52°20′	162°00′	18	8	44.44	55.56	33	0–70
50	44	8/19	51°40′	162°00′	26	12	46.15	53.85	36	5–67
51	45	8/20	51°00′	162°00′	96	38	39.58	60.42	24	8–39
52	46	8/21	50°20′	162°00′	32	12	37.50	62.50	20	0–47
53	47	8/22	49°40′	162°00′	41	10	24.39	75.61	0	0–16
54	49	8/25	50°40′	162°00′	52	18	34.62	65.38	14	0–35
55	50	8/26	51°20′	162°00′	35	18	51.43	48.57	46	20–73
56	57	9/4	52°00′	162°00′	24	5	20.83	79.17	0	0–14
57	58	9/5	51°00′	162°00′	61	20	32.79	67.21	11	0–30
58	62	9/9	51°30′	162°00′	280	109	38.93	61.07	22	13–32
GEORGE B. KELEZ					*.1 age sockeye salmon*					
59	19	7/17	51°14′	176°17′	29	19	65.52	34.48	74	46–100
60	20	7/18	51°22′	176°24′	72	52	72.22	27.78	86	70–100
61	21	7/19	50°30′	176°20′	27	23	85.18	14.82	100	90–100
62	22	7/20	50°55′	176°22′	99	78	78.79	21.21	99	86–100
63	23	7/23	51°14′	176°20′	134	110	82.09	17.91	100	95–100
64	24	7/26	51°29′	176°22′	406	293	72.17	27.83	86	79–93
65	25	7/29	51°35′	176°22′	30	23	76.67	23.33	95	71–100
66	26	7/30	51°17′	176°19′	48	37	77.08	22.92	96	77–100
67	27	7/31	50°54′	176°19′	43	29	67.44	32.56	77	55–100
68	29	8/3	50°28′	176°20′	101	57	56.44	43.56	56	40–72
69	30	8/4	51°04′	176°20′	156	98	62.82	37.12	68	56–81
70	31	8/5	51°35′	176°22′	236	154	65.25	34.75	73	63–83
71	32	8/11	51°28′	176°19′	250	149	59.60	40.40	62	52–72
72	33	8/12	51°09′	176°19′	36	19	52.78	47.22	49	23–75
73	34	8/13	50°34′	176°19′	44	19	43.18	56.82	31	7–54
74	37	8/18	51°25′	176°24′	79	53	67.09	32.91	77	60–93
75	38	8/19	51°32′	176°29′	83	51	61.44	38.56	66	49–83
76	39	8/20	51°36′	176°01′	35	23	65.71	34.29	74	49–99
77	40	8/22	51°26′	176°23′	78	41	52.56	47.44	49	31–67
78	41	8/23	51°28′	176°23′	27	20	74.07	25.93	90	63–100
79	42	8/26	51°20′	176°19′	23	10	43.48	56.52	31	0–64
80	43	8/27	51°19′	176°17′	19	6	31.58	68.42	8	0–42
81	44	8/28	51°25′	176°18′	52	42	80.77	19.23	100	86–100
82	45	8/29	51°26′	176°24′	45	32	71.11	28.89	84	63–100
83	46	8/30	51°22′	176°22′	34	26	76.47	23.53	95	72–100
84	47	8/31	51°16′	176°22′	27	23	85.18	14.82	100	90–100
85	49	9/2	50°01′	176°19′	26	14	53.85	46.15	51	20–82
86	50	9/4	50°38′	176°26′	25	15	60.00	40.00	63	32–94
87	51	9/9	51°24′	176°23′	50	42	84.00	16.00	100	93–100
88	52	9/11	50°35′	176°19′	19	15	78.95	21.05	99	70–100
					.2 age sockeye salmon					
89	13	7/7	51°17′	176°25′	19	12	63.16	36.84	69	34–100
90	14	7/8	50°49′	176°19′	32	24	75.00	25.00	92	68–100
91	19	7/17	51°14′	176°17′	88	72	81.82	18.18	100	92–100
92	20	7/18	51°22′	176°24′	213	173	81.22	18.78	100	95–100
93	22	7/20	50°55′	176°22′	75	51	68.00	32.00	78	61–95
94	23	7/23	51°14′	176°20′	70	58	82.86	17.14	100	93–100
95	24	7/26	51°29′	176°22′	177	135	76.27	23.73	94	84–100
96	26	7/30	51°17′	176°19′	82	59	71.95	28.05	86	70–100

TABLE 21. Continued.

Vessel and sample number	Set number	Date	Lat. N	Long. W	Sample size	Number of Bristol Bay type	Percentage classified: Bristol Bay type	Percentage classified: Kamchatkan type	Corrected percentage Bristol Bay type	90 percent confidence interval
97	27	7/31	50°54′	176°19′	104	67	64.42	35.58	71	57–86
98	28	8/2	50°00′	176°26′	19	9	47.37	52.63	39	2–75
99	29	8/3	50°28′	176°20′	109	46	42.20	57.80	29	14–44
100	30	8/4	51°04′	176°20′	118	70	59.32	40.68	62	47–76
101	33	8/12	51°09′	176°19′	36	26	72.22	27.78	86	63–100
102	34	8/13	50°34′	176°19′	44	28	63.64	36.36	70	47–93
103	50	9/4	50°38′	176°26′	79	50	63.29	36.71	69	52–86
104	51	9/9	51°24′	176°23′	26	17	65.38	34.62	73	44–100
105	52	9/11	50°35′	176°19′	25	17	68.00	32.00	78	49–100

TABLE 22. Average corrected percentage of immature Bristol Bay sockeye salmon by 5° of longitude and 10-day periods. Collected in 1962 aboard the vessels *Bertha Ann* and *George B. Kelez*.

Time period	165°E–170°E	170°E–175°E	175°E–180°	180°–175°W	175°W–170°W	170°W–165°W	165°W–160°W	160°W–155°W	155°W–150°W
				.1 age sockeye salmon					
July 11–20	—	—	—	—	86	87	—	—	—
July 21–31	—	—	—	100	86	—	—	—	—
Aug. 1–10	—	—	65	—	—	—	—	—	—
Aug. 11–20	—	99	—	—	—	—	—	—	—
Aug. 21–31	—	—	—	—	—	—	—	0	0
Sept. 1–10	—	—	—	—	—	—	—	4	—
Sept. 11–20	—	—	—	—	—	—	0	—	—
				.2 age sockeye salmon					
June 11–20	—	—	—	74	—	—	—	—	—
June 21–30	—	58	—	—	—	—	—	—	—
July 1–10	—	—	—	92	—	—	—	—	—
July 11–20	—	—	—	—	65	69	—	—	—
July 21–31	—	—	—	100	75	—	—	—	—
Aug. 1–10	—	—	68	—	—	—	—	—	—
Aug. 11–20	23	90	—	—	—	—	—	—	0
Aug. 21–31	—	—	—	—	—	—	—	1	—
Sept. 1–10	—	—	—	—	—	—	—	7	—
Sept. 11–20	—	—	—	—	—	—	0	—	—

CLASSIFICATION OF 1962 SAMPLES

The report for 1965 (Mason, 1967) gave the following partial results of classifying immature sockeye salmon collected in 1962: (1) Bristol Bay fish were absent in the single sample from the Gulf of Alaska; (2) between long. 175°E and long. 175°W, this type predominated after July 1; and (3) percentages of immature Bristol Bay fish decreased in samples west of long. 175°W during June 6–29 and July 1-August 22.

Table 22 summarizes (from Tables 20 and 21) the average corrected percentages of Bristol Bay type sockeye salmon by time, area, and ocean age. Their relative abundance was low (0.7 percent) in the Gulf of Alaska and west to long. 165°W, but high between long. 165°W and long. 175°E; predominance (58–100 percent) was similar in both ocean age groups. Samples from west of long. 170°E had an average of only 23 percent. Both ocean age groups as sampled

TABLE 23. Average corrected percentage of Bristol Bay type immature sockeye salmon collected south of Adak Island near long. 176°W in 1962 and 1963 aboard the vessel *Commander*.

Time period	1962	1963
	.1 age sockeye salmon	
June 1–10	—	31
June 11–20	—	34
June 21–30	47	—
July 1–10	100	48
July 11–20	72	94
July 21–31	100	100
Aug. 1–10	78	99
	.2 age sockeye salmon	
June 11–20	—	97
June 21–30	98	—
July 1–10	—	—
July 11–20	100	94
July 21–31	76	84

Table 24. Average corrected percentage of immature Bristol Bay type sockeye salmon, by distance from Aleutian Islands and 10-day periods, between long. 165°W and 175°E. Collected in 1962 aboard the research vessel *Bertha Ann*.

	Miles south of the Aleutian Islands					
Time period	0—15	16—30	31—45	46—60	61—100	100—350
			.1 age sockeye salmon			
July 11–20	—	—	100	100	77	88
July 21–31	—	—	91	—	90	74
Aug. 1–10	—	—	—	42	73	—
Aug. 11–20	—	—	—	—	—	—
Mean percentage	—	—	*96*	*71*	*80*	*81*
			.2 age sockeye salmon			
June 10–20	—	—	—	74	—	—
June 21–30	—	—	—	—	—	58
July 1–10	—	—	—	92	—	—
July 11–20	—	—	100	96	48	61
July 21–31	—	—	83	—	77	54
Aug. 1–10	—	—	—	—	68	—
Mean percentage	—	—	*92*	*87*	*62*	*58*

Table 25. Average corrected percentage of immature Bristol Bay type sockeye salmon near long. 176°W and long. 162°W, July 1–September 11, 1963.

Time period	*George B. Kelez* near long. 176°W	*Bertha Ann* near long. 162°W
	.1 age sockeye salmon	
July 1–10	—	—
July 11–20	90	—
July 21–31	91	88
Aug. 1–10	66	50
Aug. 11–20	60	56
Aug. 21–31	70	34
Sept. 1–11	78	40
	.2 age sockeye salmon	
July 1–10	80	—
July 11–20	93	—
July 21–31	88	77
Aug. 1–10	43	36
Aug. 11–20	78	30
Aug. 21–31	—	20
Sept. 1–11	73	11

near Adak Island (Table 23) evidently approached a relative maximum in July and declined thereafter.

Relative numbers of .2 age immature Bristol Bay type sockeye salmon tended to decrease with increasing distance from the Aleutian Islands. No pattern was evident for .1 age fish (Table 24).

Classification of 1963 Samples

The 1963 samples (Table 21) were taken south of the Aleutian Islands to about lat. 50°N, but only near long. 162°W and long. 176°W. Only one sample (near Adak Island) was from the Bering Sea.

The average corrected percentages of immature Bristol Bay type sockeye salmon were always higher (76 percent for .1 and .2 ages) near long. 176°W than near long. 162°W (54 percent for .1 age, 35 percent for .2 age; Table 25). The percentages of both ocean age groups near long. 176°W reached a peak in

Table 26. Average corrected percentage of immature Bristol Bay type sockeye salmon, by distance from Aleutian Islands and 10-day periods. Collected in 1963 near long. 176°W aboard the research vessel *George B. Kelez*.

	Miles south of the Aleutian Islands and lat. N				
Time period	16—30 51°35′—51°21′	31—45 51°20′—51°06′	46—60 51°51′—50°51′	61—100 50°50′—50°12′	100—111 50°11′—50°00′
			.1 age sockeye salmon		
July 11–20	86	74	99	100	—
July 21–31	90	98	77	—	—
Aug. 1–10	73	—	68	56	—
Aug. 11–20	70	49	—	31	—
Aug. 21–31	84	46	—	—	—
Sept. 1–11	100	—	—	81	51
			.2 age sockeye salmon		
July 1–10	—	69	—	92	—
July 11–20	100	100	78	—	—
July 21–31	94	93	71	—	—
Aug. 1–10	—	—	62	29	39
Aug. 11–20	—	86	—	70	—
Aug. 21–31	—	—	—	—	—
Sept. 1–11	73	—	—	74	—

TABLE 27. Average corrected percentage of immature Bristol Bay type sockeye salmon, by latitude and 10-day periods. Collected in 1963 near long. 162°W aboard the vessel *Bertha Ann.*

Time period	Lat. N			
	52°30′—53°30′	51°30′—52°30′	50°30′—51°30′	South of 50°30′
		.1 age sockeye salmon		
July 21–31	89	90	83	—
Aug. 1–10	58	45	36	—
Aug. 11–20	—	66	36	—
Aug. 21–31	—	63	35	3
Sept. 1–10	—	51	40	34
		.2 age sockeye salmon		
July 21–31	—	69	77	92
Aug. 1–10	—	36	34	—
Aug. 11–20	—	36	24	—
Aug. 21–31	—	—	30	10
Sept. 1–10	—	0	16	—

late July and declined thereafter; a sharp decrease evidently occurred in .2 age fish during early August. Percentages of Bristol Bay type sockeye salmon near Adak Island (Table 23) also reached a peak in July; the single sample from the Bering Sea (No. 15, Table 21) classified as 69 percent .1 age Bristol Bay type.

High proportions (74–100 percent) of .1 age immature fish of the Bristol Bay type occurred 16–100 miles south of the Aleutian Islands in July; percentages were lower (31–84 percent) in all areas during August (Table 26). At 16–30 and 61–100 miles, July highs of 90 and 100 percent declined to August lows of 70 and 31 percent; the values rose to 81 and 100 percent in September. Percentages of .2 age immature Bristol Bay type sockeye salmon were higher within 45 miles of the Aleutian Islands than farther

TABLE 29. Arithmetic means and (in parentheses) standard deviations of measurements

Area	Date	Sample size	Character[1]				
			14	15	16	17	18
British Columbia							
Fraser River	8/31; 9/1, 15, 16	238	24.8 (2.3)	41.3 (3.6)	58.3 (5.0)	75.6 (6.1)	93.0 (7.1)
Rivers Inlet	8/28	42	25.3 (2.3)	41.7 (3.3)	59.8 (4.2)	76.4 (5.1)	92.2 (6.4)
Bella Coola	8/2, 8, 9	326	24.7 (2.5)	41.7 (3.4)	59.9 (4.3)	76.5 (5.1)	91.6 (6.3)
Bella Bella	8/4, 10, 11	343	25.3 (2.5)	42.6 (3.8)	60.7 (4.8)	77.0 (5.5)	91.9 (6.8)
Butedale	7/27; 8/3, 4, 16, 17	306	26.3 (2.8)	44.6 (4.5)	62.9 (5.5)	79.0 (6.4)	94.0 (7.1)
Grenville	7/28; 8/9, 10, 12	301	25.0 (2.7)	42.9 (4.2)	61.2 (5.2)	77.6 (6.0)	92.8 (7.0)
Skeena River	7/12; 8/9, 10, 17, 19	119	24.6 (2.4)	42.3 (3.9)	59.8 (5.1)	76.3 (5.8)	91.0 (6.4)
Nass River	7/21, 26, 27, 28, 31; 8/3, 4, 16	312	24.9 (2.5)	43.1 (4.0)	61.5 (5.1)	79.7 (6.3)	96.1 (7.6)
Alaska							
Southeastern							
Boca De Quadra	7/28	167	26.0 (2.6)	45.5 (3.7)	63.9 (4.9)	82.3 (6.2)	99.7 (7.5)
Anan Bay	7/26	215	25.7 (2.6)	45.7 (3.6)	64.5 (4.8)	84.1 (6.1)	102.0 (7.1)
Chatham Strait	7/19	202	26.6 (2.3)	47.2 (3.4)	66.7 (4.7)	86.3 (5.8)	102.3 (6.3)
Icy Strait	7/14	198	27.1 (2.6)	47.6 (3.6)	68.1 (5.1)	87.5 (6.0)	103.5 (7.0)
Prince William Sd.	7/25	286	27.2 (2.7)	46.8 (4.0)	67.0 (5.3)	88.1 (6.2)	105.5 (7.2)
Cook Inlet (Humpy Creek)	7/22	324	24.2 (2.6)	44.1 (4.0)	66.7 (5.3)	87.5 (6.3)	104.4 (7.1)
Kodiak Island							
Uyak Bay	7/28	302	29.0 (2.8)	49.7 (4.1)	72.0 (5.4)	91.0 (6.4)	107.2 (7.2)
Olga Bay	7/26	216	24.6 (2.5)	44.9 (3.7)	67.5 (4.9)	86.8 (5.3)	103.4 (6.5)
Alaska Peninsula							
Ivanof Bay	7/19	311	26.5 (2.5)	47.8 (4.0)	71.3 (5.0)	90.6 (5.7)	108.1 (6.7)

[1] List of scale characters is given in Table 28.

to sea.

The percentage of .2 age immature fish exceeded 69 percent in all areas before August 1, reached seasonal lows in early August, and remained low thereafter.

Table 28. List of pink salmon scale characters[1].

Scale character number	Character
14	Width from center of focus to 5th circulus.
15	Width from center of focus to 10th circulus.
16	Width from center of focus to 15th circulus.
17	Width from center of focus to 20th circulus.
18	Width from center of focus to 25th circulus.
19	Width from center of focus to 30th circulus.
20	Width from 5th to 10th circulus.
21	Width from 10th to 15th circulus.
22	Width from 15th to 20th circulus.
23	Width from 20th to 25th circulus.
24	Width from 25th to 30th circulus.
25	Width from 15th to 30th circulus.
26	Width from 10th to 20th circulus.
27	Width from 20th to 30th circulus.

[1] All scales were examined at 100X magnification. Each measurement was to the nearest millimeter. All scale character numbers are the same as used by Pearson (1966 and 1967).

The percentage of .1 age immature sockeye salmon of Bristol Bay type along long. 162°W declined as the season progressed (Table 27). Percentages of this group were higher north than south of lat. 51°30′N in all time periods.

The percentages of .2 age fish were highest during July 21–31 and decreased later in all areas. Samples from north of lat. 52°30′N were too small for classification; 58–89 percent of .1 age immature fish were of the Bristol Bay type. Typically, both ocean age groups occurred together (Tables 22–27).

Comparisons Between 1962 and 1963

Samples were taken in both years near Adak Island (Tables 20, 21, and 23). Although the relative contributions of immature fish of the Bristol Bay type differed in 1962 and 1963, the peak in July and decline in August were consistent for .1 age fish. Samples of .2 age immature fish were too few to detect a difference.

Preliminary Studies of the Height of Circuli on Sockeye Salmon Scales

The height of circuli was studied on plastic impressions of scales from mature sockeye salmon by

(millimeters) of scale characters from the 1965 North American samples of pink salmon.

number[1]								
19	20	21	22	23	24	25	26	27
109.8 (8.1)	16.5 (2.3)	16.9 (2.3)	17.3 (2.4)	17.5 (2.5)	16.7 (2.1)	51.5 (5.3)	34.3 (3.8)	34.2 (3.8)
106.3 (7.0)	16.4 (2.0)	18.1 (2.4)	16.6 (1.7)	15.7 (2.6)	14.1 (2.2)	46.5 (3.9)	34.7 (3.4)	29.9 (3.4)
105.9 (6.9)	17.0 (1.8)	18.2 (2.0)	16.6 (2.1)	15.1 (2.4)	14.3 (2.2)	46.1 (4.4)	34.8 (3.2)	29.4 (3.4)
106.5 (7.6)	17.2 (2.0)	18.1 (2.2)	16.3 (2.1)	14.9 (2.6)	14.7 (2.2)	45.8 (4.6)	34.4 (3.4)	29.6 (3.5)
109.5 (8.2)	18.3 (2.5)	18.4 (2.1)	16.1 (2.3)	15.0 (2.3)	15.5 (2.9)	46.5 (4.8)	34.4 (3.5)	30.5 (3.8)
108.1 (7.6)	17.9 (2.4)	18.3 (2.3)	16.5 (2.5)	15.1 (2.4)	15.3 (2.5)	46.9 (4.6)	34.7 (3.6)	30.5 (3.5)
106.2 (7.1)	17.7 (2.3)	17.5 (2.4)	16.5 (2.1)	14.7 (2.3)	15.3 (2.5)	46.4 (4.4)	34.0 (3.6)	30.0 (3.5)
111.5 (8.4)	18.2 (2.5)	18.5 (2.4)	18.2 (2.4)	16.3 (2.5)	15.4 (2.4)	49.9 (5.0)	36.7 (3.9)	31.7 (3.6)
115.2 (8.9)	19.4 (2.4)	18.4 (2.2)	18.4 (2.2)	17.5 (2.5)	15.4 (3.0)	51.3 (5.5)	36.8 (3.6)	32.9 (4.1)
118.7 (8.3)	19.9 (2.1)	18.8 (2.1)	19.6 (2.3)	17.9 (2.4)	16.7 (2.6)	54.2 (4.8)	38.4 (3.7)	34.6 (3.6)
121.2 (7.6)	20.6 (2.1)	19.5 (2.6)	19.5 (2.4)	16.0 (2.2)	18.9 (3.5)	54.5 (4.8)	39.1 (3.8)	35.0 (4.1)
123.8 (8.2)	20.5 (2.3)	20.5 (2.8)	19.4 (2.7)	16.0 (2.3)	20.3 (3.7)	55.8 (5.1)	39.9 (4.1)	36.4 (4.5)
124.7 (8.5)	19.5 (2.4)	20.2 (2.5)	21.1 (2.4)	17.4 (2.3)	19.2 (3.4)	57.8 (5.4)	41.3 (3.7)	36.7 (4.2)
125.2 (9.1)	19.9 (2.1)	22.6 (2.3)	20.8 (2.3)	16.9 (2.1)	20.7 (3.6)	58.5 (5.5)	43.4 (3.7)	37.7 (4.5)
129.9 (8.8)	20.7 (2.2)	22.3 (2.3)	19.0 (2.3)	16.2 (2.1)	22.7 (3.5)	57.9 (5.2)	41.3 (3.6)	38.9 (4.5)
126.4 (8.1)	20.4 (2.4)	22.5 (2.3)	19.3 (2.2)	16.6 (2.5)	23.0 (3.0)	58.9 (4.8)	41.9 (3.4)	39.6 (4.3)
132.8 (8.7)	21.4 (2.5)	23.4 (2.2)	19.3 (2.0)	17.5 (2.5)	24.6 (3.2)	61.5 (5.4)	42.8 (3.3)	42.2 (4.7)

means of equipment shown in Figure 28. A typical trace of a sockeye salmon scale is shown in Figure 29. This technique is promising in terms of racial identification.

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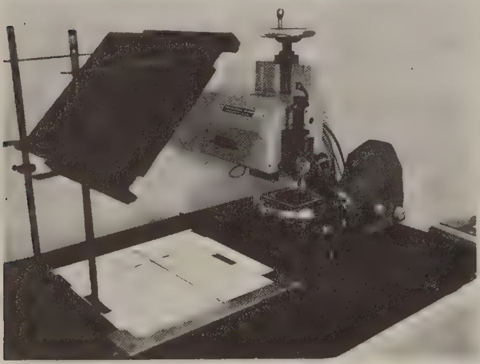


FIGURE 28. Equipment for projecting and orienting a scale image for tracing a plastic impression of a salmon scale along a selected axis by use of a profilometer. The tracing stylus is slightly above the microscope stage.

SCALE STUDIES OF PINK SALMON

by Roger E. Pearson

This report summarizes the results of studies completed in 1966. First presented are the arithmetic means and standard deviations of scale characters from 1965 collections in North America. Mean values are then compared as follows: (1) between North American samples of 1963, 1964, and 1965; and (2) between 1964 samples from North American spawning regions and the eastern North Pacific Ocean.

ARITHMETIC MEANS AND STANDARD DEVIATIONS OF SCALE CHARACTERS FROM THE 1965 COLLECTIONS IN NORTH AMERICA

Fourteen different scale measurements were obtained from the 1965 North American collections for use as racial characters (Table 28); these characters are the same as reported by Pearson (1966, 1967) for the 1963 and 1964 collections.

Arithmetic means and standard deviations of the 14 scale characters are shown for 1965 in Table 29. Mean values ranged widely among samples for all characters. Means were typically smaller in samples from British Columbia and part of southeastern Alaska (characters 16–21 and 24–27); the largest mean values were for certain characters (characters 16–19) from Uyak Bay on Kodiak Island and from the Alaska Peninsula. Other means (characters 17–19, 21, 25–27) usually increased with an increase in latitude of the spawning region.

COMPARISONS OF NORTH AMERICAN SAMPLES OF 1963, 1964, AND 1965

The mean values of scale characters in samples obtained from North American spawning regions in

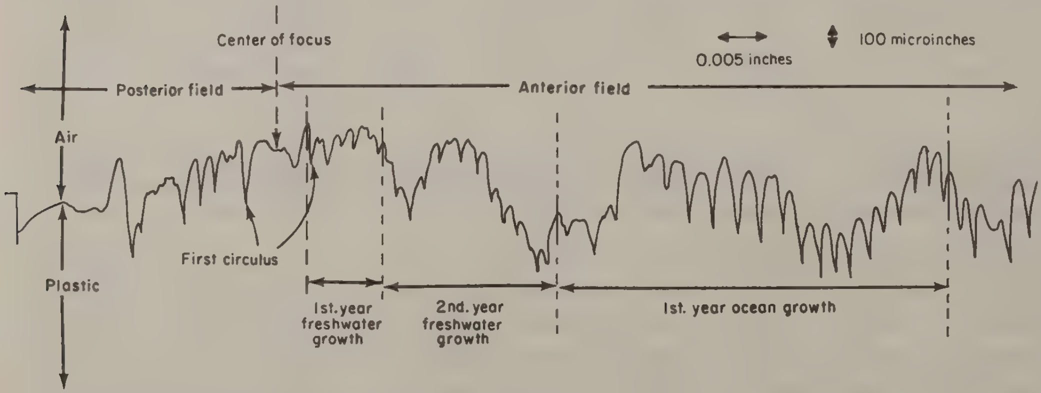


FIGURE 29. Trace of surface roughness of a plastic impression of a scale from a Naknek River sockeye salmon showing height of circuli in freshwater growth zones and first year of ocean growth.

Table 30. Arithmetic means and standard deviations of measurements of scale character 19 (width from center of focus to 30th circulus) from 1964 high seas samples.

Sample number[1]	Location		Date	Sample size[2]	Mean	S
	Latitude N.	Longitude W.				
1	44°25′	130°23′	4/17	26	112.4	11.6
2	43°36′	134°00′	4/19	66	114.4	11.0
3	52°03′	131°36′	4/19	53	107.6	12.8
4	44°30′	132°30′	4/20	51	117.4	11.6
5	45°40′	134°00′	4/21	40	118.1	10.2
6	50°48′	134°15′	4/24	97	116.6	9.1
7	50°53′	131°36′	4/25	54	117.5	10.9
8	49°28′	130°12′	4/26	91	113.5	13.1
9	47°00′	131°53′	4/27	111	109.2	10.8
10	49°41′	135°20′	4/28	64	117.0	11.3
11	48°09′	125°10′	5/4	48	102.4	9.7
12	48°00′	129°00′	5/6	74	104.8	12.3
13	48°00′	132°30′	5/7	117	112.8	10.2
14	48°00′	135°30′	5/8	89	118.1	9.7
15	47°00′	135°00′	5/9	162	116.7	11.7
16	47°00′	132°00′	5/10	173	113.9	13.3
17	47°00′	132°00′	5/11	166	115.7	13.3
18	47°00′	132°00′	5/12	103	117.2	12.4
19	47°00′	129°00′	5/13	42	122.8	11.3
20	50°38′	136°42′	5/13	66	112.6	11.2
21	50°53′	134°18′	5/14	80	115.3	13.5
22	50°47′	131°41′	5/15	46	116.0	11.7
23	45°40′	131°30′	5/16	53	120.8	14.7
24	49°30′	132°40′	5/17	107	112.0	13.4
25	49°32′	135°07′	5/18	76	119.3	11.2
26	47°51′	134°00′	5/19	164	121.0	10.6
27	48°07′	131°26′	5/20	138	111.5	14.5
28	47°00′	132°00′	5/20	96	119.7	14.7
29	47°02′	143°37′	5/24	54	124.8	9.8
30	48°39′	126°47′	5/25	129	104.4	11.9
31	48°33′	128°51′	5/26	85	105.3	14.3
32	48°37′	128°46′	5/27	40	111.2	16.7
33	55°08′	138°05′	6/8	84	121.3	10.3
34	54°45′	135°57′	6/9	208	119.6	11.3
35	57°28′	137°25′	6/14	79	119.4	10.8
36	55°00′	145°03′	6/25	55	129.5	9.1
37	55°00′	142°30′	6/27	73	124.9	10.8
38	55°02′	140°02′	6/28	154	115.8	12.6
39	55°00′	137°26′	6/29	81	116.9	12.9
40	56°32′	136°05′	6/30	113	114.5	10.6
41	57°33′	144°55′	7/9	61	120.9	12.7
42	57°30′	147°30′	7/10	94	124.8	11.3
43	57°34′	150°03′	7/11	45	126.7	11.2
44	56°58′	150°34′	7/13	61	126.8	10.4
45	55°00′	142°34′	7/17	85	121.1	16.0
46	54°58′	140°00′	7/18	54	110.4	11.4
47	55°03′	137°30′	7/19	110	108.7	12.7
48	56°20′	137°43′	7/22	49	109.6	11.2
49	52°04′	131°18′	8/6	69	102.8	9.0
50	54°10′	133°12′	8/7	99	100.1	8.4
51	55°51′	134°28′	8/8	64	106.5	9.6
52	56°30′	135°27′	8/21	73	106.6	10.7

[1] Sample numbers 1–28 and 30–32 were taken by Canadian research vessels; sample numbers 29 and 33–52 were taken by United States research vessels.

[2] Samples with 50 or more fish were originally examined; however, some scales could not be used because they had less than 30 circuli, were regenerated, or had a dirty surface.

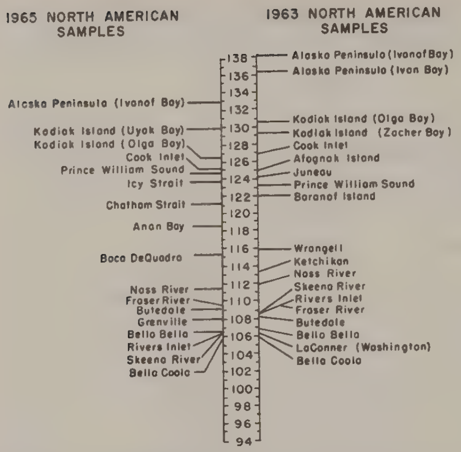


FIGURE 30. Comparisons between mean values of scale character 19 (width from center of scale focus to 30th circulus) for North American samples collected in 1965 and 1963.

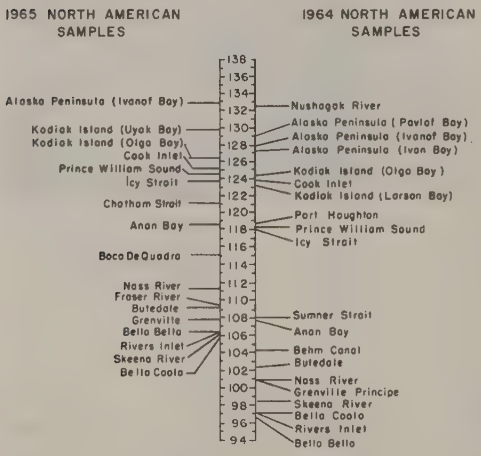


FIGURE 31. Comparisons between mean values of scale character 19 (width from center of scale focus to 30th circulus) for North American samples collected in 1965 and 1964.

1965 (Table 29) were compared with those of 1963 and 1964 (Pearson, 1966 and 1967). In the British Columbia samples, the mean values of characters 15–23, 25, and 26 typically were larger in 1963 and 1965 than in 1964. Means of most characters in Alaskan samples were also larger in 1963 and 1965. The characteristic relationship is shown in Figures 30 and 31 for character 19 (width from center of focus to 30th circulus). Here, mean values within every region were similar in 1963 and 1965. Means were smallest in both years in British Columbia or Washington samples and largest in samples from Bristol Bay and the Alaska Peninsula.

COMPARISONS BETWEEN 1964 SAMPLES FROM NORTH AMERICAN SPAWNING REGIONS AND THE EASTERN NORTH PACIFIC OCEAN

Last year, character 19 was used to classify eight samples of 100 or more fish taken in 1963 from the high seas to region of origin (Pearson, 1967). The close similarity of standard deviations of character 19 for high seas samples and for coastal samples suggests that each of the high seas samples was composed of a relatively homogeneous group of pink salmon bound for the same general coastal area.

This year, high seas samples of 1964 were examined in the same manner. Means and standard deviations of scale character 19 were obtained from all 1964 high seas samples with 50 or more mature pink salmon (Table 30). Considerable mixing of stocks evidently occurred on the high seas during 1964. For example, the largest standard deviations for spawning region samples were 9.5 and 9.9, but few high seas samples had standard deviations this small. Samples with

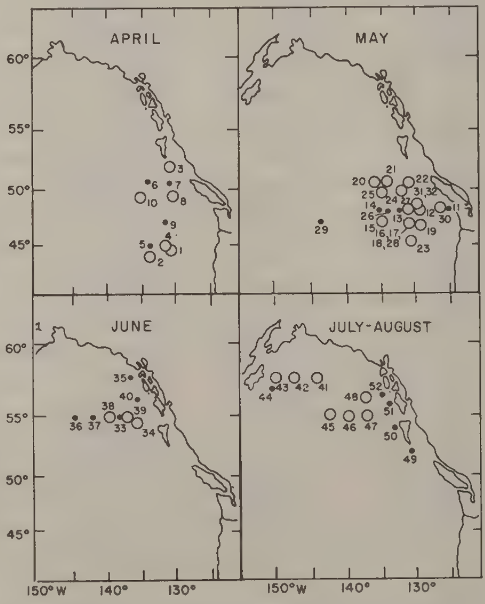
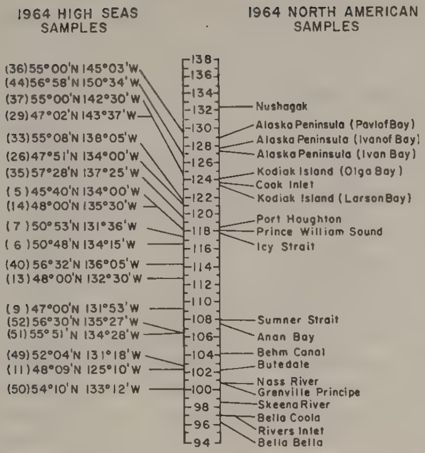


FIGURE 32. Distribution of 1964 high seas samples with 50 or more pink salmon (Table 30). Large circle indicates that the standard deviation of scale character 19 (width from center of focus to 30th circulus) exceeded 11.0.


1964 HIGH SEAS SAMPLES
1964 NORTH AMERICAN SAMPLES
(36) 55°00'N 145°03'W
(44) 56°58'N 150°34'W
(37) 55°00'N 142°30'W
(29) 47°02'N 143°37'W
(33) 55°08'N 138°05'W
(26) 47°51'N 134°00'W
(35) 57°28'N 137°25'W
(5) 45°40'N 134°00'W
(14) 48°00'N 135°30'W
(7) 50°53'N 131°36'W
(6) 50°48'N 134°15'W
(40) 56°32'N 136°05'W
(13) 48°00'N 132°30'W
(9) 47°00'N 131°53'W
(52) 56°30'N 135°27'W
(51) 55°51'N 134°28'W
(49) 52°04'N 131°18'W
(11) 48°09'N 125°10'W
(50) 54°10'N 133°12'W
138
136
134
132
130
128
126
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96
94
Nushagak
Alaska Peninsula (Pavlof Bay)
Alaska Peninsula (Ivanof Bay)
Alaska Peninsula (Ivan Bay)
Kodiak Island (Olga Bay)
Cook Inlet
Kodiak Island (Larson Bay)
Port Houghton
Prince William Sound
Icy Strait
Sumner Strait
Anan Bay
Behm Canal
Butedale
Nass River
Grenville Principe
Skeena River
Bella Coola
Rivers Inlet
Bella Bella

FIGURE 33. Linear comparison of mean values of scale character 19 (width from center of focus to 30th circulus) from 1964 North American spawning region samples and 1964 high seas samples that had standard deviations less than 11.0. Locations of high seas samples are shown by number in Figure 32 and Table 30.

standard deviations on the order of 10.0–11.0 probably consisted of mixed stocks, but the majority of fish were most likely from the same general coastal region (Pearson, 1967). Character 19 was used to classify relatively homogeneous groups of pink salmon to region of origin: samples with standard deviations larger than 11.0 were therefore not examined (Figure 32).

Mean values from high seas samples with standard deviations less than 11.0 and from North American coastal samples are shown in Figure 33. The figure shows the following similarities between means of numbered high seas samples and of those from coastal regions: (1) 11, 49, and 50, British Columbia and the southern part of southeastern Alaska; (2) 9, 13, 51, and 52, southeastern Alaska; (3) 5, 6, 7, 14, 26, 33, 35, and 40, northern part of southeastern Alaska, Prince William Sound, Cook Inlet, and Kodiak Island; (4) 29 and 37, Cook Inlet and Kodiak Island; and (5) 36 and 44, Alaska Peninsula or Nushagak.

SUMMARY AND CONCLUSIONS

Arithmetic means and standard deviations of 14 scale characters were calculated from the 1965 collections of pink salmon in North America. No Asian scales were examined. The ranges in mean value varied widely for all characters. Means were typically smaller in samples from British Columbia and the southern part of southeastern Alaska.

The mean values of scale characters in samples obtained in 1965 from North American spawning regions were compared with those of the 1963 and 1964 samples. The mean values of most scale characters were larger in 1963 and 1965 than in 1964. In all years, the mean values of certain characters became progressively larger with an increase in latitude of the spawning region.

Mean values of scale character 19 (width from focus to 30th circulus) were obtained from 52 samples of 50 or more mature pink salmon collected during 1964 in the eastern North Pacific Ocean. The scale data suggested considerable mixing of stocks in at least 33 of the 52 samples. Mixing was not evident in 1963.

Mean values of the other 19 samples (those that gave no evidence of mixing) were compared with values of 1964 samples from coastal spawning regions. The mean values of three high seas samples were similar to mean values in British Columbia and southeastern Alaska samples. Four high seas samples had means like those of southeastern Alaska. Eight resembled the samples from the northern part of southeastern Alaska, Prince William Sound, Cook Inlet, and Kodiak Island. Two were like Cook Inlet or Kodiak Island, and two were most similar to Alaska Peninsula or Nushagak samples.

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POPULATION DYNAMICS

by R. A. Fredin, G. Hirschhorn, and S. Murai

Biometric research on the dynamics of exploited fish stocks of the North Pacific Ocean and Pacific coast of North America during the past year included a study of time changes in biomass of eastern Bering Sea king crabs, the development of analytic procedures for forecasting the size of Bristol Bay sockeye salmon runs one to three weeks before they enter the Bay, and an analysis of statistics from the Japanese mothership salmon fishery.

TIME CHANGES IN BIOMASS OF EASTERN BERING SEA KING CRABS

From recoveries of male adult king crabs tagged by United States scientists between 1955 and 1961, Hirschhorn (MS 1966) estimated growth rates, size-

TABLE 31. Japanese mothership salmon fishery—catch, fishing effort, and catch per unit effort—long. 160°E to 175°W—1952–65.

Year	Species of salmon					
	Sockeye[1]	Pink[2]	Chum[1]	Coho[3]	Chinook[1]	Total[1]
			Catch—Thousands of fish			
1952	738	698	629	24	1	2,091
1953	1,534	2,892	2,678	307	3	7,414
1954	3,382	2,698	8,254	675	57	15,071
1955	9,456	9,108	14,012	1,467	43	34,164
1956	8,702	6,589	15,316	3,393	117	34,170
1957	19,403	17,204	8,877	193	25	46,042
1958	10,708	7,859	14,048	3,106	38	35,832
1959	9,125	18,642	12,856	1,388	63	42,326
1960	12,879	1,826	10,517	862	180	26,324
1961	12,998	3,226	6,128	281	31	22,704
1962	10,590	1,011	6,372	1,531	122	19,755
1963	8,902	6,242	5,858	1,890	88	23,475
1964	7,097	2,198	8,640	3,533	410	21,964
1965	12,038	4,238	6,037	1,173	185	23,864
			Fishing effort—Thousands of tans			
1952	471	394	471	199	471	471
1953	1,314	1,027	1,314	619	1,314	1,314
1954	2,547	2,265	2,547	1,253	2,547	2,547
1955	5,761	4,511	5,761	2,392	5,761	5,761
1956	8,729	6,908	8,729	3,629	8,729	8,729
1957	6,213	4,180	6,213	1,467	6,213	6,213
1958	7,207	5,628	7,207	2,681	7,207	7,207
1959	7,096	5,957	7,096	2,433	7,096	7,096
1960	6,518	5,921	6,518	3,079	6,518	6,518
1961	4,994	4,538	4,994	1,494	4,994	4,994
1962	5,851	4,918	5,851	2,231	5,851	5,851
1963	5,954	5,186	5,954	2,494	5,954	5,954
1964	7,518	6,586	7,518	3,926	7,518	7,518
1965	6,110	5,165	6,110	2,420	6,110	6,110
			Catch per unit effort—Number of fish per tan			
1952	1.57	1.77	1.34	0.12	0.0021	4.44
1953	1.17	2.82	2.04	0.50	0.0023	5.64
1954	1.33	1.19	3.24	0.54	0.0224	5.92
1955	1.64	2.02	2.43	0.61	0.0075	5.93
1956	1.00	0.95	1.75	0.93	0.0134	3.91
1957	3.12	4.12	1.43	0.13	0.0040	7.41
1958	1.49	1.40	1.95	1.16	0.0053	4.97
1959	1.29	3.13	1.81	0.57	0.0089	5.96
1960	1.98	0.31	1.61	0.28	0.0276	4.04
1961	2.60	0.71	1.23	0.19	0.0062	4.55
1962	1.81	0.21	1.09	0.69	0.0209	3.38
1963	1.50	1.20	0.98	0.76	0.0148	3.94
1964	0.94	0.33	1.15	0.90	0.0545	2.92
1965	1.97	0.82	0.99	0.48	0.0303	3.79

[1] May–August. [2] June–August. [3] July–August.

Sources: 1952–1960, Manzer *et al.* (1965); 1961–1965, INPFC Statistical Yearbooks.

related natural mortality and catchability coefficients, and changes in biomass with age. He also examined changes in the size composition and relative abundance of male king crabs caught by Japanese factoryships in the eastern Bering Sea. The following summarizes that study.

The distribution in biomass over most of the fishable life span of a cohort of king crabs having a carapace length of 135 mm at recruitment indicates that the optimum potential yield, in terms of the growth-mortality balance, is associated with catches of males of about 160 mm mean carapace length.

Length frequency distributions of samples of male king crabs in the Japanese factoryship catches in eastern Bering Sea indicate that the mean carapace length has shifted gradually from 170 mm in 1953 to 154 mm in 1965. Evidently, the size at capture of most animals now harvested is below that associated with optimum potential yield.

Catch-per-unit-effort statistics for the Japanese fishery indicate that the abundance of king crabs of the optimal size group in eastern Bering Sea decreased by about two-thirds between 1959–60 and 1963–64. A more precise determination of the decrease, as well as the formulation of an optimum harvesting policy, requires additional information on (1) the fishing power of all segments of the fishery, (2) technological improvements in fishing gear and methods, and (3) gear competition.

Methods of Forecasting Bristol Bay Sockeye Salmon Runs

United States scientists have predicted Bristol Bay sockeye salmon runs since the late 1950's. These forecasts, made in November of each year and based on indices of abundance of Bristol Bay sockeye salmon at various life history stages, were reasonably accurate through the early 1960's. The forecasts during the past few years, however, have been less accurate.

In an attempt to obtain a later and accurate forecast, we developed a method for predicting the size of the Bristol Bay sockeye salmon run one to three weeks in advance of the fishing season in the Bay. The method is based on the relationship between the estimated rate of exploitation of maturing Bristol Bay sockeye salmon by the Japanese mothership salmon fishery and the percentage of .2 age fish in the Bristol Bay run. Its use requires an adjustment for variation in fishing effort, an estimate of the percentage of .2 age fish expected in the Bristol Bay return, and catch and effort statistics for the mothership fishery by 10-day periods in May and June of the year of return.

May-June forecasts were made for 1965 and 1966. The 1965 forecast, based on incomplete high seas fishery statistics through June 10, indicated a return of 32–46 million fish rather than of 27 million fish as predicted by previous methods in November of 1964. As ascertained later, complete catch and effort statistics through June 10 would have given a forecast of 56 million fish. The total run in 1965 was about 61 million fish.

The forecast of November 1965 was 24–34 million sockeye salmon in the Bristol Bay run of 1966. The figure of 24 million was later increased to 33 million. Three separate forecasts based on estimates of high seas catches and fishing effort through May 31, June 10, and June 20 indicated a run of 6–17 million fish. Preliminary statistics indicate that the total 1966 run was about 20 million fish.

Results of forecasting the 1965 and 1966 runs from high seas fishery statistics in May and June clearly indicate the need for improved accuracy if such forecasts are to aid fishery management and industry planning. Steps to be taken in this direction include modifications in the analytic procedure and an at-

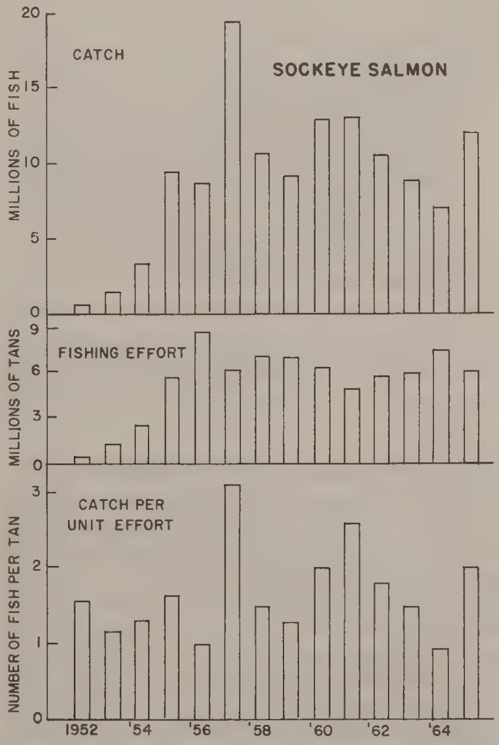

Figure 34. Sockeye salmon catch, fishing effort, and catch per unit effort, Japanese mothership salmon fishery, long. 160°E to 175°W, 1952–65 (entire season).

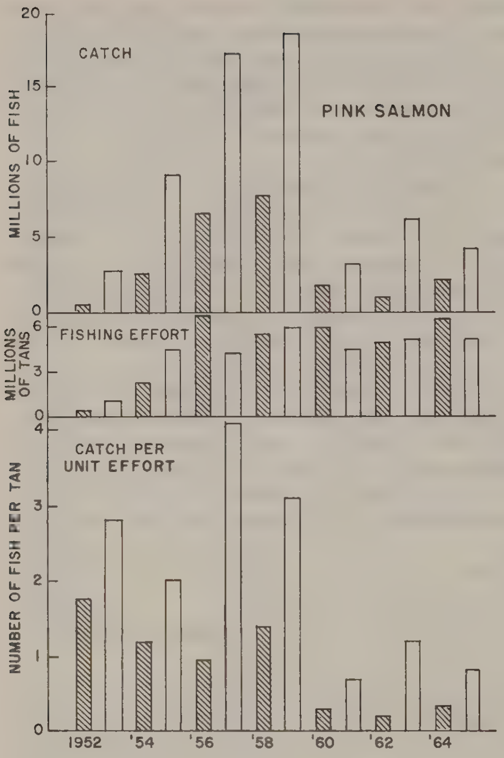

FIGURE 35. Pink salmon catch, fishing effort, and catch per unit effort, Japanese mothership salmon fishery, long. 160°E to 175°W, 1952–65 (June–August). Shading indicates even-year cycles.

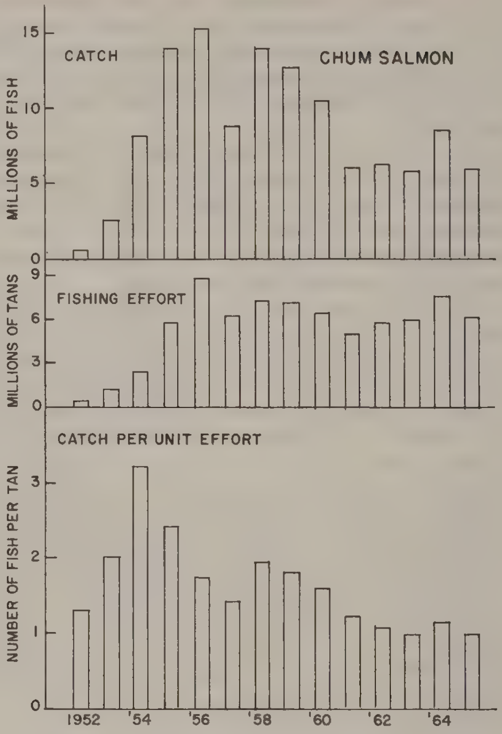

FIGURE 36. Chum salmon catch, fishing effort, and catch per unit effort, Japanese mothership salmon fishery, long. 160°E to 175°W, 1952–65 (entire season).

tempt to incorporate into the forecasting system available measures of environmental factors affecting the ocean distribution of maturing Bristol Bay sockeye salmon.

JAPANESE MOTHERSHIP SALMON FISHERY STATISTICS

Statistics on annual catch, fishing effort, and catch per unit effort for the Japanese mothership salmon fishery in 1965 (INPFC Statistical Yearbook for 1965) are listed with corresponding data for 1952–60 (Manzer *et al.*, 1965) and 1961–64 (INPFC Statistical Yearbooks for 1961–1964) by species in Table 31. The statistics for the 14-year period are shown in Figures 34–38 for sockeye, pink, chum, coho, and chinook salmon, respectively.

Catch and catch-per-unit-effort statistics for various periods and areas in 1965 mentioned in the following discussions of the five species are derived from the INPFC Statistical Yearbook for 1965.

Sockeye Salmon

The catch of 12 million sockeye salmon in 1965 was the largest since 1961 and the fourth largest on record (Figure 34). Approximately one-half of the catch was made east of long. 175°E in late May and June; about one-third was taken west of long. 170°E after June 10. Most of the remaining catch was made between long. 170°E and 175°E before June 20.

As indicated by catch per unit effort (Figure 34), the abundance of sockeye salmon in 1965 in the mothership fishing area was the greatest in four years. Largest concentrations were between long. 180° and 175°W in late May and June.

Pink Salmon

Except for 1961, the 1965 pink salmon catch was the lowest for an odd-numbered year since 1955, the first year in which the mothership fishery was fully developed (Figure 35). Approximately three-fourths of the catch was made west of long. 175°E after June

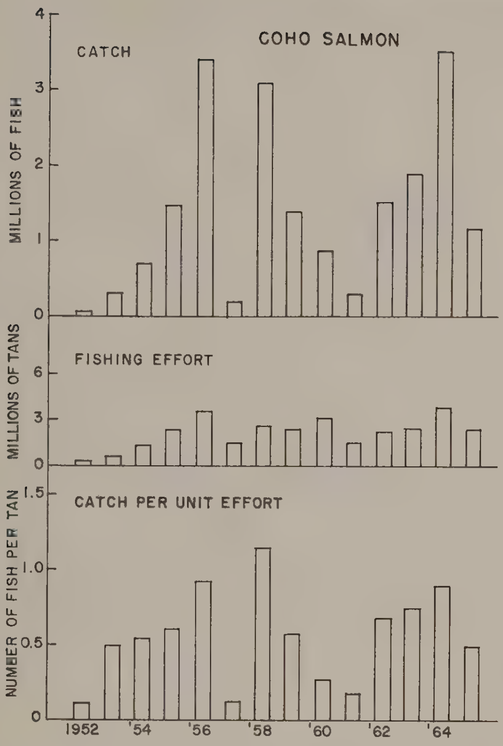

Figure 37. Coho salmon catch, fishing effort, and catch per unit effort, Japanese mothership salmon fishery, long. 160°E to 175°W, 1952–65 (July–August).

10. The area east of long. 175°E accounted for about 25 percent of the catch in 1965. This percentage was substantially greater than in previous years. The largest concentrations of pink salmon were west of long. 175°E, north of lat. 56°N, in late June and early July.

Chum Salmon

The 1965 catch of chum salmon was about the same as the average catch for 1961–64 (Figure 36). Chum salmon were caught in every area and time period in which motherships fished. The largest catches were made east of long. 175°E, south of the Aleutian Islands, in late May; between long. 165°E and 170°E, lat. 48°N to 54°N, in mid-June; and east of long. 180°, north of lat. 56°N, in late June.

Chum salmon remained at a low level of abundance in 1965, as indicated by the catch per unit effort for the mothership fishing area as a whole (Figure 36). South of the Komandorskiy and Aleutian Islands and throughout the fishing season, the abundance of chum salmon decreased from west to east; north of lat. 56°N, chum salmon were separated into two groups after June 20—one east of long. 175°E and the other west of long. 170°E—175°E.

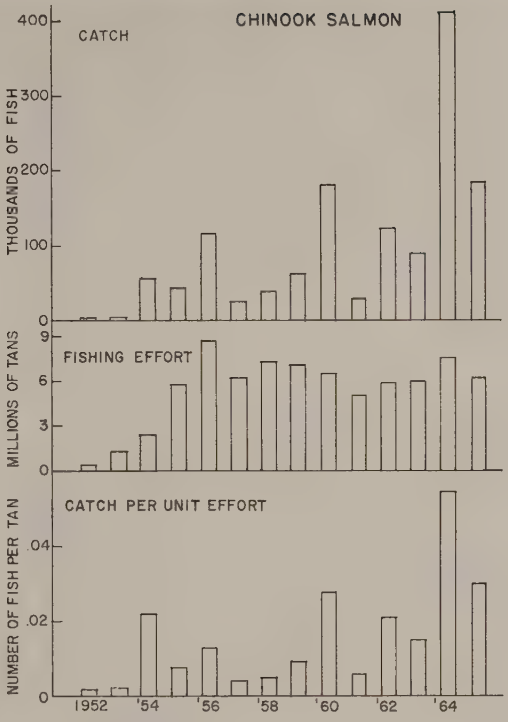

Figure 38. Chinook salmon catch, fishing effort, and catch per unit effort, Japanese mothership salmon fishery, long. 160°E to 175°W, 1952–65 (entire season).

Coho Salmon

The 1965 catch of coho salmon was considerably below the 1964 catch (Figure 37). Part of the reduced catch in 1965 can be ascribed to the lack of fishing by the mothership fleet in August; however, the 1965 catch was also lower than in 1962 or 1963 when there was no fishing in August. Approximately 80 percent of the 1965 catch was made south of lat. 48°N in July.

The abundance of coho salmon was lower than in any of the three preceding years (Figure 37). It appeared that coho salmon entered the mothership fishery area from the south or east in early July, and that a portion of those which entered the fishing area west of long. 175°E moved to the west and north by late July.

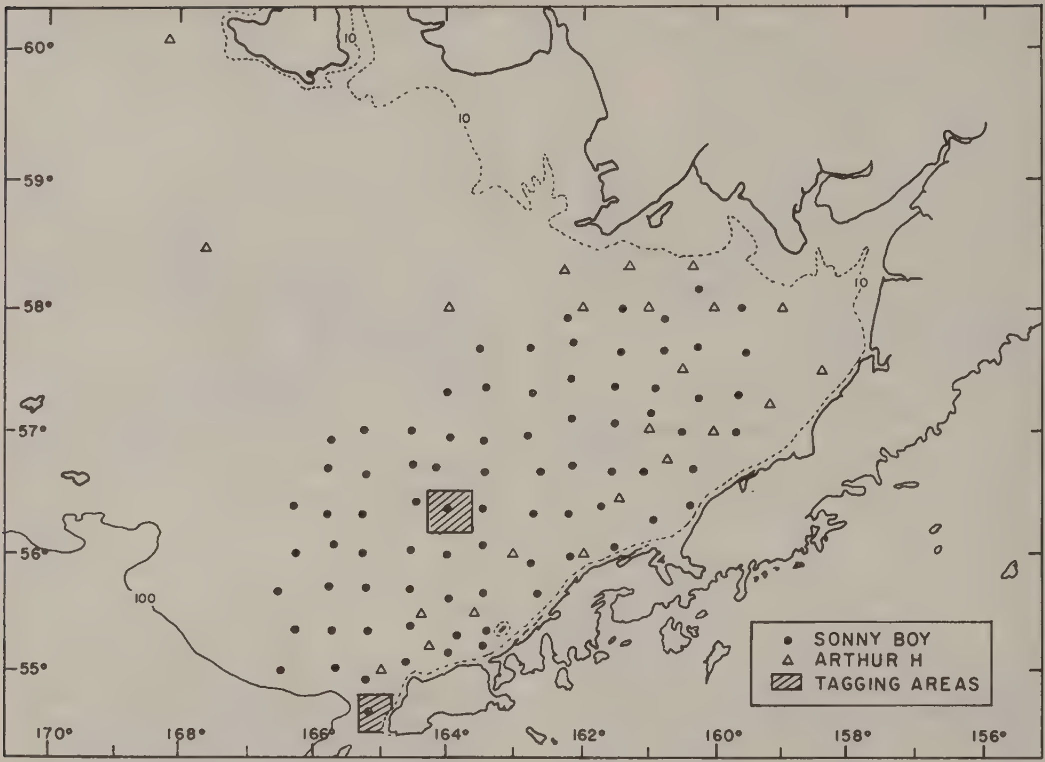

FIGURE 39. Research vessel station locations and tag release areas, Bering Sea king crab investigations, 1966.

Chinook Salmon

The 1965 catch of chinook salmon was the second largest on record but far below that of 1964 (Figure 38). About 60 percent were taken north of lat. 56°N after June 20. Most of the remainder were taken west of long. 175°E, south of the Aleutian and Komandorskiy Islands.

The abundance of chinook salmon available to the mothership fishery was the second greatest on record (Figure 38). Principal areas of abundance were north of lat. 56°N, after June 20, and also south of lat. 48°N, after July 1.

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KING CRAB RESEARCH

by James B. Kirkwood and James F. Hebard

The objective of this research is to determine the maximum sustainable yield of king crabs in the southeastern Bering Sea. Distribution, reproduction, growth, mortality, and environmental factors affect abundance; they must be examined. In 1966, the United States conducted an extensive survey and tagged adult males. An observer was aboard the Japanese factoryship *Dainichi Maru* from June 15 to September 6; he sampled the size composition of the commercial catch and collected data similar to those reported for 1965 (Kirkwood, 1967).

Trawling and tagging from the 75-foot trawler *Sonny Boy* during May 16–August 16 were the first extensive field activities since 1961. One-hour drags of a standard, 400-mesh, eastern otter trawl were made at 80 stations located 20 miles apart (Figure 39). Similarity of the station pattern and sampling methods to those of 1957–61 (Simpson and Shippen, MS 1966) permitted comparisons with earlier results. In addi-

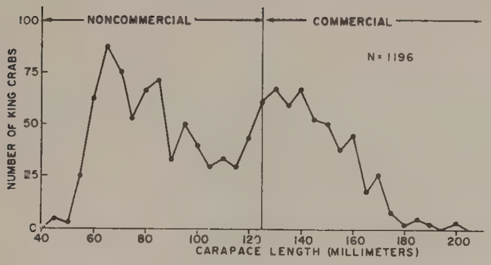

FIGURE 40. Carapace length frequency (millimeters) of king crabs sampled in the Bering Sea, 1966.

tion to catch data on king crabs, the temperature, salinity, bottom type, and associated animals were recorded at each station.

Size frequency of the Bering Sea king crabs in 1966 (data collected on the *Sonny Boy*) is shown in Figure 40. Measurements of carapace widths were converted to length (Rickey and Sheridan, 1963) and broadly divided into commercial (over 125 mm length) and noncommercial categories.

One major mode occurred in each category in 1966. For noncommercial crabs, minor modes are indicated at 65, 85, and 95 mm. King crabs of commercial size were present to a length of 200 mm, and evidently were most abundant in the range 125–145 mm.

Between June and August 1966, 5,400 tagged male crabs were released to the fishery. Of these, 5,096 were tagged and released from the *Sonny Boy* during the trawling survey and mass tagging (Figure 39). The other 344 crabs were released from the chartered vessel, *Arthur H.*, of the International Pacific Halibut Commission. The importance of reporting complete recovery information for recaptured specimens was emphasized to scientists studying king crabs in Japan and the U.S.S.R.

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Made in United States of America
Reprinted from Copeia, 1967, No. 3, September 1
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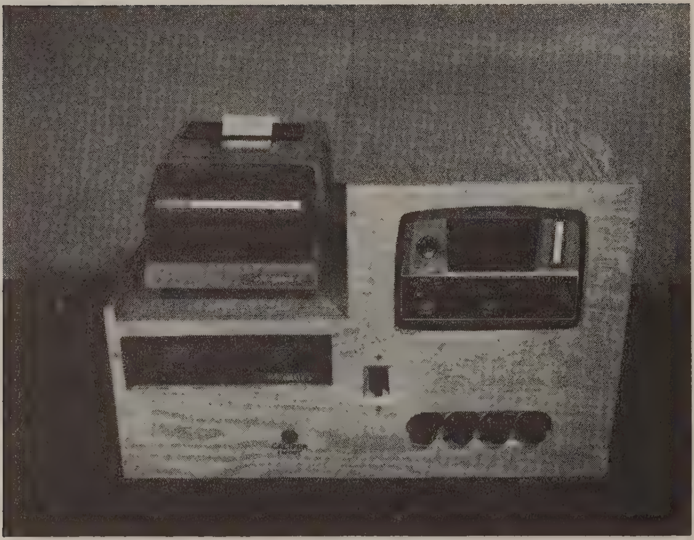
DIGITAL CALIPER.—The large number of measurements needed to describe fully the characteristics of biological specimens and other objects has always been tedious and time consuming. The work can be done much more rapidly and with greater accuracy with a digital caliper recently developed by us.

The digital caliper (Fig. 1) is a new electronic instrument built to measure objects precisely throughout the range of 0.1 mm to 1.0 m. Calipers of several different discrete sizes make it possible to select the most convenient unit for the particular range of length and degree of accuracy desired. The



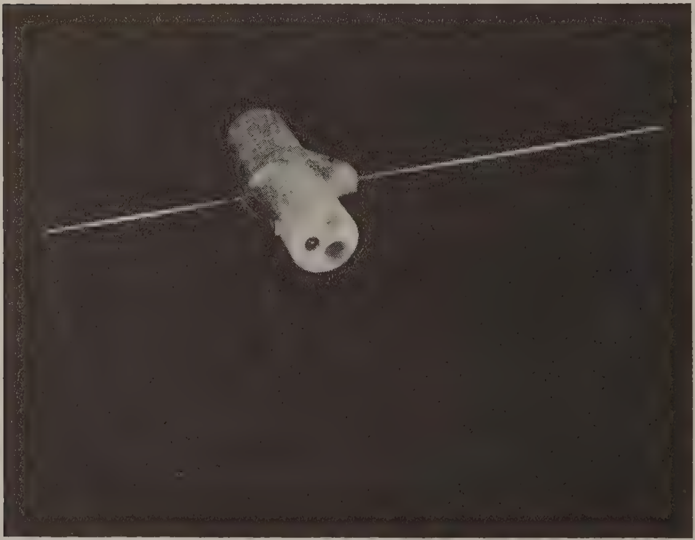


Fig. 1. Digital caliper. Upper. Cabinet containing printer with printed tape protruding from the top, left side; voltmeter, upper right; and a 4-digit specimen identification coder, lower right. The identification code numbers appear in the 4 left-hand columns of the print-out. The 4 right-hand columns give the measurements. Lower. Caliper with flexible connecting cord.

calipers consist of two major components, (1) a hand-held measuring unit (Fig. 1 lower) similar to the standard vernier caliper and (2) a separate digital voltmeter-printer (Fig. 1 upper) connected to the caliper by a lightweight flexible cord. The measuring unit illustrated comprises a 46-cm, D-shaped rack-and-pinion; a vernier thumb drive; and a balanced double handle that can be operated by either hand. One handle contains a small multi-turn helical potentiometer and the other a bearing assembly. The cord provides a regulated 40-volt source to the potentiometer winding and returns signals to the digital voltmeter. A push button on the handle of the digital caliper, or a foot treadle, initiates a voltmeter printout representing the position of the potentiometer slidewire.

The slidewire length and the nonlinearity of resistance introduced by the placement of the potentiometer's individual loop segments limit the instrument's sensitivity and accuracy. The "independent linearity" in small potentiometers is about 0.05% or one part in 2000. The voltage can be adjusted to cause the voltmeter to read in even metric units.

The voltmeter shown has a 4- and a 40-volt range, which allows full-scale readout of 4 or 40 cm with a resolution of one part in 4000, and an accuracy of about 0.2 mm. Accuracy over a smaller range can be doubled by proper voltage adjustment appropriate for the length range.

The voltage source is a transformer rectified with a double zener stabilized bridge, and it can be operated from ordinary unregulated a-c line voltage.

The caliper fits comfortably into either hand and can be held at any angle required by the contour or position of the object to be measured. It may also be attached to a stationary object, such as a ring stand, and zeroed in on a particular spot from which a series of measurements is to emanate. This arrangement is especially suitable for measuring small specimens under the microscope, and much more efficient than using a mechanical stage on which the measurement is not a direct reading, but the difference between two readings.

The new instrument is ideal when a lengthy series of measurements is being made because the user need not interrupt the measuring process to record data. Instead, each measurement appears automatically on a visual display and, by means of a push button, can also be printed simultaneously on tape, giving a permanent, four-digit record. An additional four-digit number is printed to identify the specimen. Use of the printer unit provides an instant, legible transcript, and also eliminates errors in reading scales and in copying data.

Because of its versatility, the digital caliper has wide application. It can be used in the laboratory, aboard ship, and at field stations, wherever alternating current is available. In fishery research laboratories, the digital caliper reduces the cost and increases the accuracy of morphometric measurements. It can do the same for measurements of the diameters of the annuli of scales for growth studies. Furthermore, wet, fresh fish and other aquatic animals can be measured in the field with the digital caliper by one man. He can handle the specimens with one hand, hold the calipers in the other hand, and activate, with a foot treadle, the print-out which gives a clean, permanent record. When the data recorded on the print-out tapes are to be analyzed by computer, prior coding makes the tapes ready immediately for the card-punch operator.

A prototype instrument, now being used at the U. S. Bureau of Commercial Fisheries Biological Laboratory in Ann Arbor, Michigan, includes all of the features described in this paper. The price of the components of this instrument supplied by Arthur D. Little, Inc., including development costs, was $1,975. Information about the availability of similar instruments can be obtained by corresponding with the junior author.

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Proceedings of the National Shellfisheries Association
Volume 57 — June 1967

EFFECTS OF "SOFT" DETERGENTS ON EMBRYOS AND LARVAE OF THE AMERICAN OYSTER (*CRASSOSTREA VIRGINICA*)

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ABSTRACT

Experiments were designed to determine the toxicity to oyster embryos and larvae of a standard linear alkylate sulfonate (LAS) detergent, a commercial liquid LAS detergent, and sewage effluent with and without degradation products of LAS. The percentage of fertilized eggs developing normally was reduced significantly at concentrations greater than 0.025 mg/l of the standard LAS and 0.25 mg/l of the commercial detergent. The percentage survival and growth of larvae decreased significantly at 1.00 and 0.50 mg/l, respectively, for LAS and at 2.50 mg/l for the liquid detergent. Although growth of oyster larvae was decreased by concentrations of 100 ml per liter of effluent with or without LAS, the reduction was not drastic except at concentrations of 200 ml per liter or higher. The toxicity, if any, of the degradation products of LAS was masked by the toxicity of the effluent itself.

INTRODUCTION

The quantities of synthetic detergents used in the United States and the effects of such detergents on freshwater animals were reviewed by Hidu (1965), who also reported the effects of some detergents on larvae of the marine bivalves, *Mercenaria mercenaria* and *Crassostrea virginica.* An industry-wide conversion was completed on June 30, 1965, from the manufacture of detergents of the alkyl benzene sulfonate (ABS) type, which are only very slowly degraded by bacterial action, to the new biodegradable linear alkylate sulfonate (LAS) type (Brenner, 1965). The effects of these new "soft" detergents on freshwater fish have been studied by Bardach, Fujiya and Holl (1965), Hokanson[1] (personal communication), and Thatcher and Santner[2] (personal communication). Since these detergents are almost completely degraded in an efficient sewage treatment plant, most of the detergent occurs in the effluent as degradation products rather than as the active detergent. Field tests have shown that LAS-based detergents break down rapidly when subjected to secondary (activated sludge) sewage treatment (Renn, 1965).

In the present study we determined the toxicity of a reference sample of undegraded LAS detergent, a commercial liquid biodegradable detergent, and of sewage effluents, both with and without degradation products of the detergent, to embryos and larvae of the American oyster, *Crassostrea virginica.*

METHODS AND MATERIALS

The methods of obtaining fertilized oyster eggs and oyster larvae and the standard method for rearing the larvae in the laboratory were described by Loosanoff and Davis (1963).

To determine the effect of various concentrations of pollutants on development of eggs into normal free-swimming larvae, we placed about

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13,000 recently fertilized eggs into each of a series of 1-liter beakers that contained filtered, ultraviolet-treated sea water. In all experiments, duplicate 1-liter cultures were maintained at each concentration of the detergent or effluent and two cultures were left untreated as controls. All cultures were kept in a constant temperature bath at 26.0° ± 1.0°C. After 48 hours, the free-swimming, straight-hinge larvae from each beaker were caught on a 325-mesh screen and resuspended in 250 ml of filtered sea water. A 4-ml sample of the resuspended larvae was then obtained from each beaker. The number of eggs developing normally in each culture was determined by counting the total number of straight-hinge larvae in each sample. The counts of samples from duplicate cultures were averaged and the results expressed as a percentage of the average number developing in control cultures. The values in the tables are the averages for three successive experiments except where noted.

To determine the effects of the detergents or effluents on survival and growth of larvae, we placed 10,000 to 12,000 larvae, which had been reared under normal culture conditions for 48 hours, into each of a series of 1-liter beakers containing filtered ultraviolet-treated sea water. The sea water was changed every second day to eliminate waste products of larval metabolism, and the experimental conditions were reestablished. Equal volumes of a mixture of live algal food (flagellates) were added to each culture daily, as described by Davis and Guillard (1958). A standard dose of Sulmet[3] (0.33 ppm) was added to each culture every second day, when the sea water was changed, to minimize mortality due to bacterial contamination.

To determine the percentage survival and increase in size of oyster larvae after 10 days under the experimental conditions, i.e., when the larvae were 12 days old, we sampled quantitatively in a manner similar to that at 48 hours. The number of surviving larvae in each 4-ml sample was counted and 100 larvae were measured. The average number surviving and the average length were determined for each pair of duplicate cultures. Survival is expressed as a percentage of survival in control cultures and increase in size is given as a percentage of the increase in mean length of larvae in untreated control cultures. The values in the tables are the averages for three successive experiments except where noted.

The sample of LAS was obtained from The Soap and Detergent Association, 295 Madison Avenue, New York, New York 10017, and was "a composite of a number of commercially available products, typical of the LAS presently being marketed" (letter from the Association, June 2, 1965). Analysis of the sample was 60.8 per cent LAS, 36.1 per cent sodium sulfate, 0.4 per cent free oil, and 2.7 per cent water. A sample of a commercial liquid biodegradable detergent of unknown composition was also used. A modified geometric series of test concentrations was used for both detergents: 0.0025, 0.005, 0.010, 0.025, 0.05, 0.10, 0.25, 0.50, 1.00, 2.50, 5.00, and 10.00 mg/l.

For tests of degradation products of LAS, the U.S. Testing Company, Hoboken, New Jersey 07030 (where biodegradability tests of LAS were in progress), furnished us with sewage effluents in which 81.25 per cent, 96.25 per cent, and 100 per cent of the 20 mg/l of added LAS detergent had been degraded. For the control effluent, i.e., effluent that contained no detergent degradation products, U.S. Testing Company took effluent just prior to adding detergent to the digestion process. Larval cultures were set up with effluent containing degradation products equivalent to original LAS concentrations of 0.1, 0.2, 2.0, 3.0, 4.0, and 5.0 mg/l, which meant that it was necessary to add 5, 10, 100, 150, 200, and 250 ml of effluent, respectively, per liter of larval culture. Another series of cultures was set up with equivalent volumes of effluent that contained no detergent degradation products to determine whether it was the degradation products or the effluent itself that affected the survival and growth of larvae.

EFFECTS OF LAS DETERGENTS AND THEIR DEGRADATION PRODUCTS ON OYSTER EMBRYOS AND LARVAE

Effects on Embryonic Development

The effect of active LAS detergents and sewage effluent, both with and without degraded LAS, on the development of fertilized oyster eggs into straight-hinge larvae is given in Table 1. Oyster eggs had a very low tolerance to active LAS detergent; concentrations of 0.05 and 0.10 mg/l permitted only 51 and 64 per cent, respectively, of the eggs to develop, and many of these were of abnormal shape or size, or both. No eggs developed at a concentration of 0.25 mg/l. Hidu (1965) reported that 47 per cent of oyster eggs developed normally at a concentration of 0.50 mg/l of ABS that was 54.8 per cent active, i.e., at an ABS concentration of 0.27 mg/l. It would appear that LAS is more toxic than ABS while in the active state.

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[3] Registered Trademark — American Cyanamid Company's sodium sulfamethazine soluble powder.

TABLE 1. *Percentage of oyster eggs developing to straight-hinge larvae in various concentrations of LAS detergent and sewage effluent (see Methods and Materials for explanation of percentages).*

Concentration (mg/l)	LAS[1]	Liquid biodegradable[2] detergent	Effluent with degraded LAS	Effluent[3] without degraded LAS	Volume of effluent (ml/l)
0.0 (Controls)	100	100	100	100	0 (Controls)
0.0025	92	99	—	—	—
0.005	88	108	—	—	—
0.010	85	108	—	—	—
0.025	66	118	—	—	—
0.05	51[4]	115	—	—	—
0.10	64[4]	68	—	—	—
0.20	—	—	127	78	10
0.25	0	63	—	—	—
0.50	0	14	—	—	—
1.00	0	0	—	—	—
2.00	—	—	97	109	100
2.50	0	0	—	—	—
3.00	—	—	—	—	—
4.00	—	—	—	—	—
5.00	0	0	99[4]	66[4]	250
10.00	0	0	—	—	—

[1] Concentrations listed are of active LAS; gross product contained 60.8% active LAS

[2] Concentrations listed are of gross product; percentage of active LAS unknown

[3] Values listed based on single experiment

[4] Many larvae in these cultures abnormal in size or shape, or both

In experiments with the commercial liquid biodegradable detergent, oyster embryos tolerated reasonably well a concentration as great as 0.25 mg/l of the gross product, i.e., survival was equal to 63 per cent of that in the controls. The manufacturer will not divulge the percentage composition of this product, but its lower toxicity was undoubtedly the result of a lower concentration of active LAS. Hidu (1965) reported that oyster eggs developed to straight-hinge larvae at a concentration as high as 1.00 mg/l of the same brand of detergent with an ABS base, again indicating that LAS is more toxic than ABS while in the active state.

The toxicity of effluent from a sewage treatment process did not increase when it contained LAS (Table 1). Although a high percentage of eggs developed at a concentration of 5.00 mg/l, many of the resulting larvae were abnormal. The data clearly show that LAS had lost most of its toxicity to oyster eggs through degradation in treatment; any remaining toxicity of the LAS or its degradation products was masked by the toxicity of the effluent itself.

Effect on Survival and Growth of Larvae

Oyster larvae showed a somewhat higher tolerance to both standard LAS and the commercial liquid biodegradable detergent than did the embryos. Survival of larvae decreased significantly between concentrations of 0.50 mg/l and 1.00 mg/l for the LAS and between 1.00 mg/l and 2.50 mg/l for the commercial product (Table 2). The results again are similar to those obtained by Hidu (1965) with ABS detergents. Although the percentage survival of larvae in the control cultures was somewhat greater than in cultures receiving the effluent with or without degraded LAS, a degradation-product concentration equivalent to 4.00 mg/l of the undegraded LAS was required before survival was drastically reduced. (Our supply of control effluent without LAS was limited: therefore, fewer concentrations could be tested than for effluent with degraded LAS.) The

TABLE 2. *Percentage of oyster larvae surviving in various concentrations of LAS detergent and sewage effluent (see Methods and Materials for explanation of percentages).*

Concentration (mg/l)	LAS[1]	Liquid biodegradable[2] detergent	Effluent with degraded LAS	Effluent[3] without degraded LAS	Volume of effluent (ml/l)
0.0 (Controls)	100	100	100	100	0 (Controls)
0.0025	76	96	—	—	—
0.005	106	88	—	—	—
0.010	93	102	—	—	—
0.025	71	104	—	—	—
0.05	96	84	—	—	—
0.10	104	120	78	—	5
0.20	—	—	76	75	10
0.25	95	95	—	—	—
0.50	63	82	—	—	—
1.00	0	87	—	—	—
2.00	—	—	69	103	100
2.50	0	42	—	—	—
3.00	—	—	63	—	150
4.00	—	—	35	—	200
5.00	0	0	10	19	250
10.00	0	0	—	—	—

[1] Concentrations listed are of active LAS; gross product contained 60.8% active LAS

[2] Concentrations listed are of gross product; percentage of active LAS unknown

[3] Values listed based on single experiment

similarity of results for effluent with and without detergent degradation products suggests that any toxicity of the degradation products was masked by toxicity of the digested sewage effluent.

As indicated by the percentage increase in mean length (Table 3), growth of oyster larvae was normal at LAS concentrations of 0.0025 mg/l to 0.25 mg/l, but broke sharply between 0.25 mg/l and 0.50 mg/l of active LAS; all larvae died at concentrations of 1.00 mg/l or higher. The liquid detergent was somewhat less toxic but growth of larvae declined between detergent concentrations of 1.00 mg/l and 2.50 mg/l. The lesser toxicity was again probably due to a lower concentration of active LAS in the commercial detergent. These results are similar to those reported by Hidu (1965) for non-biodegradable detergents containing ABS.

Growth of larvae was approximately normal at concentrations of 100 ml/l (2.00 mg/l) or less in both the control sewage effluent and that containing degraded LAS. Slight growth occurred in the cultures receiving effluent containing degradation products at a concentration equivalent to 4.00 mg/l of undegraded LAS. Since one-fifth of the total volume of these cultures was effluent (200 ml/l) and the effluent without degradation products appeared to be equally toxic, we assume that LAS detergent in sewage, if passed through an effective sewage treatment plant, should have no more effect than an equal volume of effluent without LAS detergent degradation products.

SIGNIFICANCE OF DETERGENTS TO OYSTER FISHERIES

Although LAS detergents are known to be more readily biodegraded than ABS detergents. little has been published concerning the toxicity of LAS detergents or their degradation products. It has been generally assumed that the degradation products would be non-toxic.

Our results indicate that LAS detergents, in the active state, are at least as toxic to oyster larvae as the ABS compounds. Passage through an effective sewage treatment plant should, however, almost completely degrade LAS detergents,

TABLE 3. *Percentage increase in mean length of oyster larvae reared in various concentrations of LAS detergent and sewage effluent.*

Concentration (mg/l)	LAS[1]	Liquid biodegradable[2] detergent	Effluent with degraded LAS	Effluent[3] without degraded LAS	Volume of effluent (ml/l)
0.0 (Controls)	100	100	100	100	0 (Controls)
0.0025	96	100	—	—	—
0.005	97	101	—	—	—
0.010	98	101	—	—	—
0.025	106	100	—	—	—
0.05	94	102	—	—	—
0.10	96	103	111	—	5
0.20	—	—	105	92	10
0.25	88	101	—	—	—
0.50	31	103	—	—	—
1.00	Dead	100	—	—	—
2.00	—	—	85	71	100
2.50	Dead	44	—	—	—
3.00	—	—	55	—	150
4.00	—	—	32	—	200
5.00	Dead	Dead	—[4]	—[4]	250
10.00	Dead	Dead	—	—	—

[1] Concentrations listed are of active LAS; gross product contained 60.8% active LAS

[2] Concentrations[1] listed are of gross product; percentage of active LAS unknown

[3] Values listed based on single experiment

[4] Number surviving too small for accurate determination of mean length

thereby reducing their toxicity and rendering them safer to use than the ABS detergents. There is need, nevertheless, for data on the quantity of active LAS that may enter our streams and estuaries, comparable to data on ABS.

We found that effluent containing LAS degradation products equivalent to 20 mg/l of LAS is no more toxic to oyster eggs and larvae than an equal volume of effluent containing no degradation products. Thus, if sewage treatment plants are capable of degrading LAS compounds, it would require enough effluent to constitute 15 per cent or more of the total volume of streams and estuaries to affect seriously the development, survival, and growth of oyster larvae. In most areas a 15 per cent concentration of sewage effluent would not be expected, but in areas such as the immediate vicinity of sewage discharge where sewage effluent approaches or exceeds 15 per cent of the total volume of the body of water it enters, it could be expected to affect recruitment of oysters.

CONCLUSIONS

1. The percentage of fertilized oyster eggs developing normally was reduced significantly at concentrations greater than 0.025 and 0.25 mg/l of active LAS and a commercial liquid biodegradable detergent, respectively.

2. The percentage survival of larvae decreased significantly at 1.00 mg/l for LAS and at 2.50 mg/l of the liquid detergent.

3. Growth of oyster larvae was significantly reduced at 0.50 mg/l for LAS and at 2.50 mg/l of the liquid detergent.

4. Although growth of oyster larvae was decreased by concentrations of 100 ml per liter of effluent with or without LAS, the reduction was not drastic except at concentrations of 200 ml per liter or higher.

5. The toxicity, if any, of the degradation products of LAS was masked by the toxicity of the effluent itself.

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Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Made in United States of America
Vol. 96, No. 1, 20 January 1967
pp. 60–62

Scale Development in the Gulf Menhaden, *Brevoortia patronus*

ROBERT B. CHAPOTON

Scale Development in the Gulf Menhaden, *Brevoortia patronus*

As part of the Bureau of Commercial Fisheries research on menhaden in the Gulf of Mexico, the pattern and sequence of scale formation were studied in larval and juvenile Gulf menhaden, *Brevoortia patronus*. Suttkus (1956) reported that a Gulf menhaden measuring 26.8 mm standard length (or about 30 mm fork length) possessed scales, but he did not indicate their location or extent. This report provides information on the manner of scalation and minimum size of fully scaled individuals. Such information facilitates the use of scales in determining ages and computing growth.

Sample material consisted of 146 menhaden collected along the Texas coast in April 1964 and April 1965, and distributed about evenly over a range of 15 to 35 mm fork length. The specimens were cleared in a 3% solution of hydrogen peroxide for about 1 hr and then stained with alizarin red to facilitate identification of scales.

Two species of menhaden occur along the Texas coast, the Gulf (largescale) menhaden, which is by far the predominant commercial species, and the finescale menhaden, *B. gunteri*. The juveniles and adults of these species can be readily identified (Hildebrand, 1963), but not their larvae. Arnold et al. (1960) concluded that the larval menhaden in collections from Galveston Entrance during 1953–58 were Gulf menhaden because only this species, as juveniles and adults, had ever been observed in the Galveston area. Since my material was collected in the same locale, I made the same assumption.

The largest fish without any scales measured 22 mm, the smallest with at least one scale, 21 mm. The first scales form single rows on the sides of the belly between the pectoral and pelvic fins (Figure 1). The fork lengths and scalation of fish were as follows: 21 to 22 mm—scales only along the belly; 22 to 23 mm—three or four rows of scales on the lower lateral surfaces of the body from a point above the base of the pectoral fin posteriorly to the anal fin, and a single row on the caudal peduncle; 23 to 24 mm—scales

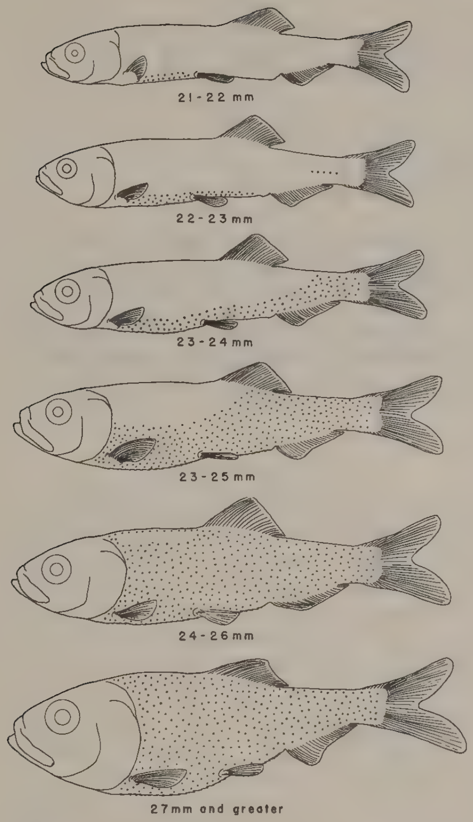

FIGURE 1.—Sequence of scale formation in *Brevortia patronus.* Speckling indicates area where scales occur.

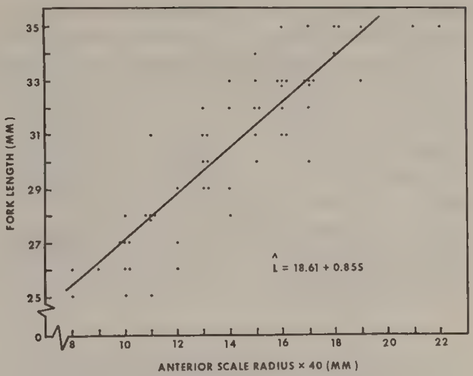

FIGURE 2.—Relation of fork length of fish and anterior scale radius in juvenile *Brevoortia patronus.*

cover the caudal peduncle as well as the area just above the vent and along the base of the anal fin; 23 to 25 mm—scales cover the remaining area below a line from the insertion of the dorsal fin to a point located midlaterally just behind the head (Figure 1 clearly indicates that scales of fish in this size range continue to appear anteriorly and dorsally); and 24 to 26 mm—fully scaled except for a small area of the back on each side of the paired rows of predorsal scales. The smallest fully scaled fish measured 25 mm; all fish 27 mm and larger were completely scaled.

No measurable difference was observed in the sequence or extent of scalation between fish collected in 1964 and those collected in 1965. Measurements of scale number, diameter, and location indicate that scales on both sides of the same fish appeared and developed at about the same rate. Newly formed scales on fish 21 to 22 mm are elliptical, granular, and translucent, have no circuli or ctenii, and measure from 0.32 to 0.45 mm in greatest dimension. On fish 22 to 23 mm, the scales behind the pectoral fins decrease in size posteriorly from 0.45 to 0.14 mm diameter, whereas those on the caudal peduncle are larger posteriorly and decrease anteriorly from 0.23 to 0.14 mm. On fish 23 to 25 mm, scales 0.40 to 0.45 mm in diameter are imbricated.

Scales on the lateral surfaces form in diagonal rows corresponding to the myotomes. Those above the horizontal skeletogenous septum are arranged diagonally and slant dorsally and posteriorly, whereas those below the septum slant ventrally and posteriorly. Scales on the back, along the belly, around the opercular cover, and near the fin bases are not evenly spaced but appear bunched. These scales are generally smaller than those on the lateral surfaces and usually are of irregular shape.

To determine the average relation between size of fish and size of their scales, I examined the scales of 58 menhaden 25 to 35 mm long. The scales were removed from the midlateral area just forward of the dorsal fin. The regression of fork length (L) on scale size (S) proved linear and is expressed by the equation $L = 18.61 + 0.85\ S$ (Figure 2).

These findings are important for two reasons: First, because the Gulf menhaden is generally considered to be a winter-spawning fish (Hildebrand, 1963; Suttkus, 1956) and scales have been shown on young-of-the-year collected in April, it may now be safely assumed that scales from larger and older individuals carry growth histories that begin with the first spring of life. Second, the intercept value of 18.61 (19) permits more accurate calculation of growth of scales of Gulf menhaden.

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Journal of Geophysical Research Vol. 72, No. 2 January 15, 1967

Long-Wave Radiation near the Hawaiian Islands

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Long-wave thermal radiation was measured nightly at the sea surface in the Hawaiian Islands area with a Suomi-Kuhn radiometer during two periods in 1965. By applying the Stefan-Boltzmann law to measurements of upward long-wave radiation, effective emissivity for seawater was determined to be 0.99, a value somewhat higher than had previously been considered. The data suggest the need for a revision of the cloud-correction formula for determining mean net radiation. Averages of data taken at half-hour intervals yield representative values for net radiation. In the Hawaiian Islands region, net long-wave radiation measurements range from 0.04 ly min^{-1} for an overcast sky to 0.12 ly min^{-1} for a clear sky.

Introduction

An important factor in the complex balance of energy between the ocean and the atmosphere is the flux of long-wave radiation across the sea surface. An estimate of this flux is necessary in calculating the heat budget of the ocean. Many measurements of long-wave radiation have been made over land masses, but very few have been made over oceans, particularly in low latitudes. Data are needed for verifying or correcting existing empirical formulas for average exchange values and for estimating the magnitude of changes in the instantaneous radiation measured at sea.

As part of a study of the annual variations in processes that alter the distribution of properties in the sea, the Trade Wind Zone Oceanography Pilot Study of the U. S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, measured long-wave radiation from sea and sky on cruises near the Hawaiian Islands from March through June 1965. Since few earlier direct measurements were available, the initial measurements for the period March–June were made as a survey to verify empirical formulas applied in the Hawaiian Islands region. Results from the first set of observations indicated the need for a second set of observations taken under more carefully controlled conditions. During September 1965 extensive measurements were obtained to substantiate the information from the March–June series while the Bureau ship *Townsend Cromwell* lay at anchor off Barbers Point, Oahu, Hawaii. The results presented in this paper are based on the data from the 360 observations taken during the two periods.

Methods

A Suomi and Kuhn long-wave radiometer, which has been described in detail by *Suomi and Kuhn* [1958] was used. It consists of a sensor manufactured by the Johnson Service Company of Milwaukee, Wisconsin, and a simple bridge circuit. The instruments were calibrated at the Honolulu Biological Laboratory in January and again in August of 1965.

The sensor was mounted on a thin rod and positioned 2 m from the sea surface and about 2 m from the side of the ship. The measurements, made at night, consisted of separate measurements of long-wave radiation from the sea surface and the sky. Sky conditions, winds, sea and air temperatures at the interface, relative humidity, and atmospheric pressure were observed from the ship near the time of each radiation measurement. Measurements were not made during rain or wind greater than 25 knots.

These instruments have not been used extensively at sea. Different procedures and precautions were taken during different phases of the project to evaluate the instrument for work in the open ocean.

For the first set of observations, measurements were taken routinely each night while the ship was underway at reduced speed during plankton tows and bathythermograph observations. Between observations the radiometer was stored in a ventilated enclosure on the deck of the ship, so that the instrument had a temperature essentially that of air. The instrument was held in the observation position for 5 min before reading to allow it to come to equilibrium.

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During the second set of observations the ship was not underway. An observation was taken every half hour, two different radiometer heads being interchanged periodically. Some measurements were taken with the sensing surfaces of one instrument reversed to check any bias that might have been introduced if the same surface had always been directed toward the water. Meteorological conditions were monitored continually rather than every 4 hours, as was normally done during the March–June series.

The radiation was calculated using equations presented by *Suomi et al.* [1958] and *Kuhn* [1961]:

$$R_i = \sigma T_i^4 + [C_1(T_i + T_j) + C_2] \cdot (T_i - T_j) - [C_3(T_A + T_i) + C_4] \cdot (T_A - T_i) + \Delta T_{i,j}\,(\text{time}) \tag{1}$$

where R_i is the radiation measured by the radiometer in g cal cm^{-2} min^{-1} (ly min^{-1}); T_i, T_j, and T_A are the temperatures in degrees Kelvin of the two sensing heads and the instrument (air); and the subscripts ($i = 1, 2$ and $j = 2, 1, i \neq j$) indicate which surface is being considered: 1 for that aimed at the sea surface and 2 for that aimed toward the sky. The Stefan-Boltzmann constant, σ, is 0.817×10^{-10} cal cm^{-2} min^{-1} deg^{-4}, and the four constants are

$$C_1 = 2.745 \times 10^{-6} \qquad C_2 = 1.804 \times 10^{-3}$$

$$C_3 = 5.49 \times 10^{-6} \qquad C_4 = 3.608 \times 10^{-3}$$

Although the theoretical accuracy of the instrument is limited by random error in the sensor thermistors to ±5%, individual measurements can be more accurate. The instruments were individually calibrated and used over a narrow range of temperature. Because many observations were made, conclusions were based on averages over a large number of values.

The proximity of the sensing head to the ship may produce a slight error in the measurements due to hull radiation. For most of the observations, however, both the air and the hull temperatures were nearly that of the water. Even though the part of the hull subtended by the radiometer in this case may have been more than in *Boudreau*'s [1965] experiment, the negligible temperature difference between water and ship's hull would have a negligible effect on the radiation from the sea.

Since no oceanic measurements of long-wave radiation are available for the central Pacific, the results of the measurements are presented here. The data are presented in a graphical manner, the observed points being connected by lines for continuity. Additional data on position, cloud cover, and wind for each day of the March–June series are summarized in tabular form in the figures.

EFFECTIVE EMISSIVITY OF THE SEA SURFACE

For the range of temperatures encountered in the sea, the ocean radiates heat very nearly as a blackbody. The radiation relation, a modification of the Stefan-Boltzmann law, can be written as

$$R_w = \epsilon \sigma T_w^4 \tag{2}$$

where R_w is the radiation from the sea surface with a temperature of T_w (°K). The emissivity ϵ, a measure of the efficiency of emission, is 1 for a blackbody. The emissivity of seawater has been estimated by various authors to be as much as 10% less than that of the perfect radiator; the mean was taken by *Boudreau* [1965] to be about 0.96.

If R_w and T_w are known, it is possible to calculate the effective emissivity, which includes both the effects of emission and reflection of sky emission. If the temperature of the mixed surface layer (determined by bucket temperature) is taken as that of the surface layer, the influence of the 0.1 mm 'cool skin,' which Boudreau stated controls the effective radiation of the body, will be neglected. A surface skin temperature less than that measured in the surface mixed layer would raise the apparent value of the emissivity, calculated from R_w and T_w, by an amount controlled by the temperature difference. Conversely, emissivity would be less if a thin warm layer, due to diurnal heating, were present.

The effective emissivity was calculated from radiometer measurements and bucket temperatures, which were the only surface temperature values available. The air and water temperatures usually were nearly equal; during the September series the difference was always less than 1°K. An average value of ϵ for each series of observations was obtained by averaging all the individual values for each series of observations. The value for ϵ determined in this manner for the 180 September observations was 0.99 ± 0.007 (range, slightly less than 0.98 to slightly greater than 1.00).

Although variation in the values of ϵ for the March–June series was higher than for the September series, the mean for the nearly 180 observations in the March–June period was also 0.99 (range, 0.96 to above 1.1). The Weather Bureau observations during the Equalant program ('Sea Surface Radiation Temperatures' by Stanley D. Soules, unpublished manuscript, personal communication) were used for similar calculations and gave essentially the same results.

It appears that at the time of observation, conditions were not favorable for the formation of a 'cool skin,' since the presence of a lower temperature in the surface layer would raise the apparent value of ϵ and increase the departure from the values estimated previously. This effect would indicate that the sea radiates as a perfect blackbody. The diurnal heating may allow a warmer thin surface layer to form, indicating a lower effective emissivity. To reduce the calculated values for ϵ from 0.99 to 0.96, however, would require a surface temperature about 2.3°C higher than that assumed from the bucket value. These observations were made under natural sea and current conditions (i.e., the surface film was constantly remixed with the larger water mass below it).

A few of the measurements were taken under conditions in which the conduction terms—the second and third terms on the right side of equation 1—were negligible. This circumstance eliminated the error which would have been present if the constants used had been incorrect. Radiation calculations for these cases yielded results no different from the calculations in which the conduction terms were significant.

Long-Wave Radiation from the Sea and Sky

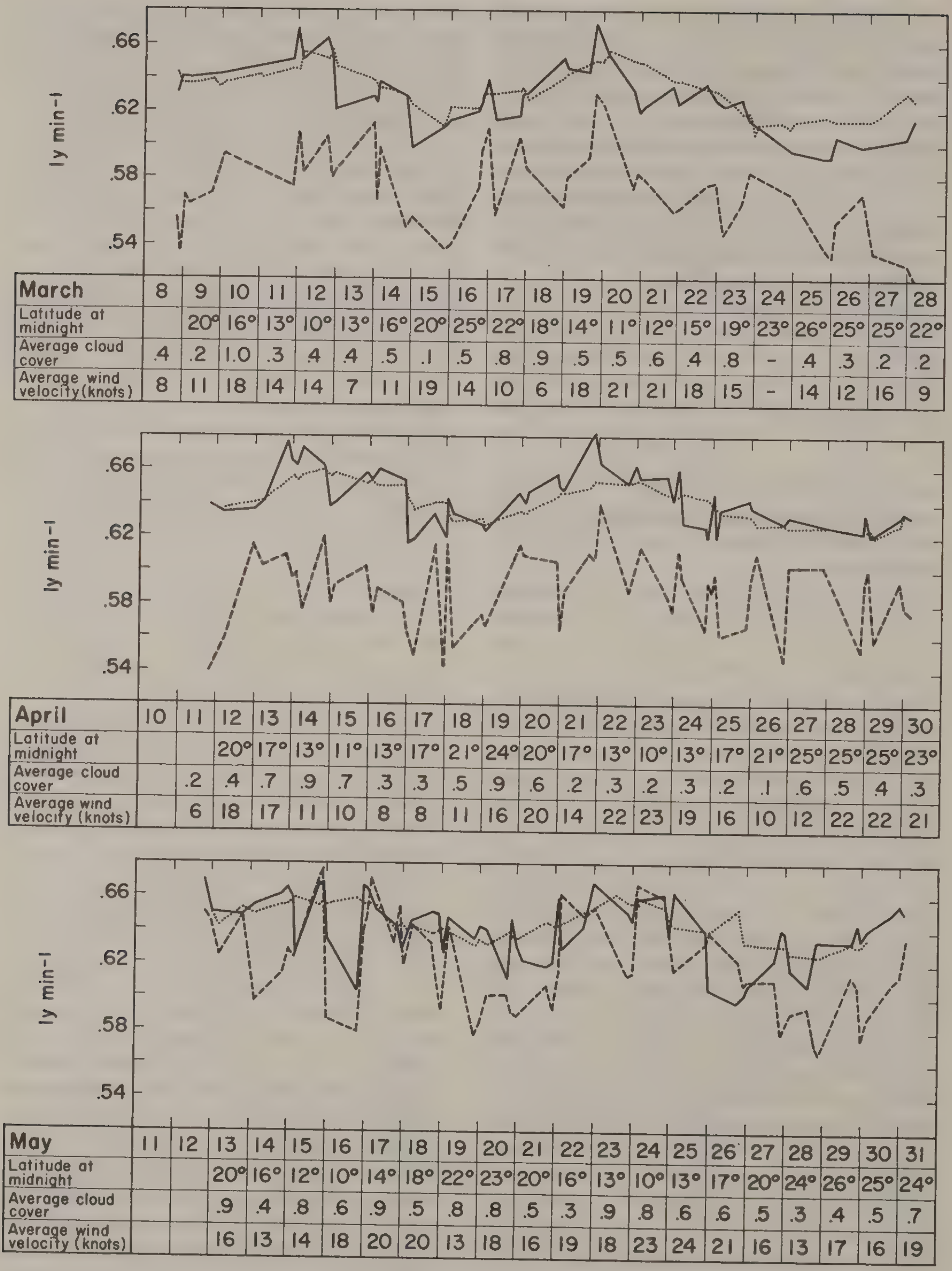
The long-wave radiation emitted by the sea surface can be estimated by using the sea surface temperature in the region of interest and the emissivity determined above. For the Hawaiian region, *Seckel* [1962] estimated an annual temperature range which gives long-wave radiation emitted by the sea from about 0.62 ly min^{-1} during the cool season to about 0.66 ly min^{-1} during the warmer period. The September values are near the upper limit and March values are near the lower limit. Figures 1 and 2 summarize the data taken during the March–June series by month and the September series by day. The periodicity apparent in Figure 1 is due to the change in sea surface temperature resulting from the change in latitude during the cruise.

Radiation from the sky can be determined from the air temperature and a value for effective emissivity. Emissivity from the sky, a function of the vapor pressure of water, is not easily determined, however. The measured long-wave radiation emitted by the sky shows variation that is not apparent in the measured vapor pressure and air temperature. This variation was due to variation in the cloud cover and, perhaps, to variation in the thickness of the humid air mass.

The cloud cover is an important factor in the radiation from the sky. The data indicate that the radiation is affected only by the condition of the sky directly above the meter. During the September series, when cloud cover overhead was observed carefully, the cloud condition frequently could be classified as either clear or overcast. At night it is difficult to discern thin clouds, but the clouds were usually opaque, though type was not determined.

In a few instances during the September series, the cloud condition changed abruptly from clear to overcast. Figure 2*f* shows an occasion on which the sky became overcast abruptly near 2200 hours and remained obscured until about 2400 hours. The cloud cover sharply increased the radiation from the sky but had a limited effect on the sea surface radiation. Each time this distinct change was observed, the difference between the radiation from clear sky and overcast sky was about 0.06 ly min^{-1}.

On different dates, however, the value of the clear sky radiation was different. During three days of the September series, the clear sky



March	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Latitude at midnight		20°	16°	13°	10°	13°	16°	20°	25°	22°	18°	14°	11°	12°	15°	19°	23°	26°	25°	25°	22°
Average cloud cover	.4	.2	1.0	.3	.4	.4	.5	.1	.5	.8	.9	.5	.5	.6	.4	.8	-	.4	.3	.2	.2
Average wind velocity (knots)	8	11	18	14	14	7	11	19	14	10	6	18	21	21	18	15	-	14	12	16	9

April	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Latitude at midnight			20°	17°	13°	11°	13°	17°	21°	24°	20°	17°	13°	10°	13°	17°	21°	25°	25°	25°	23°
Average cloud cover		.2	.4	.7	.9	.7	.3	.3	.5	.9	.6	.2	.3	.2	.3	.2	.1	.6	.5	.4	.3
Average wind velocity (knots)		6	18	17	11	10	8	8	11	16	20	14	22	23	19	16	10	12	22	22	21

May	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Latitude at midnight			20°	16°	12°	10°	14°	18°	22°	23°	20°	16°	13°	10°	13°	17°	20°	24°	26°	25°	24°
Average cloud cover			.9	.4	.8	.6	.9	.5	.8	.8	.5	.3	.9	.8	.6	.6	.5	.3	.4	.5	.7
Average wind velocity (knots)			16	13	14	18	20	20	13	18	16	19	18	23	24	21	16	13	17	16	19

Fig. 1. Long-wave radiation for cruises during the Trade Wind Zone Oceanography Pilot Study, March–May 1965. R_w (solid line), radiation from the sea surface; R_s (broken line), radiation from the sky; σT_w^4 (dotted line), radiation calculated from the surface water temperature.

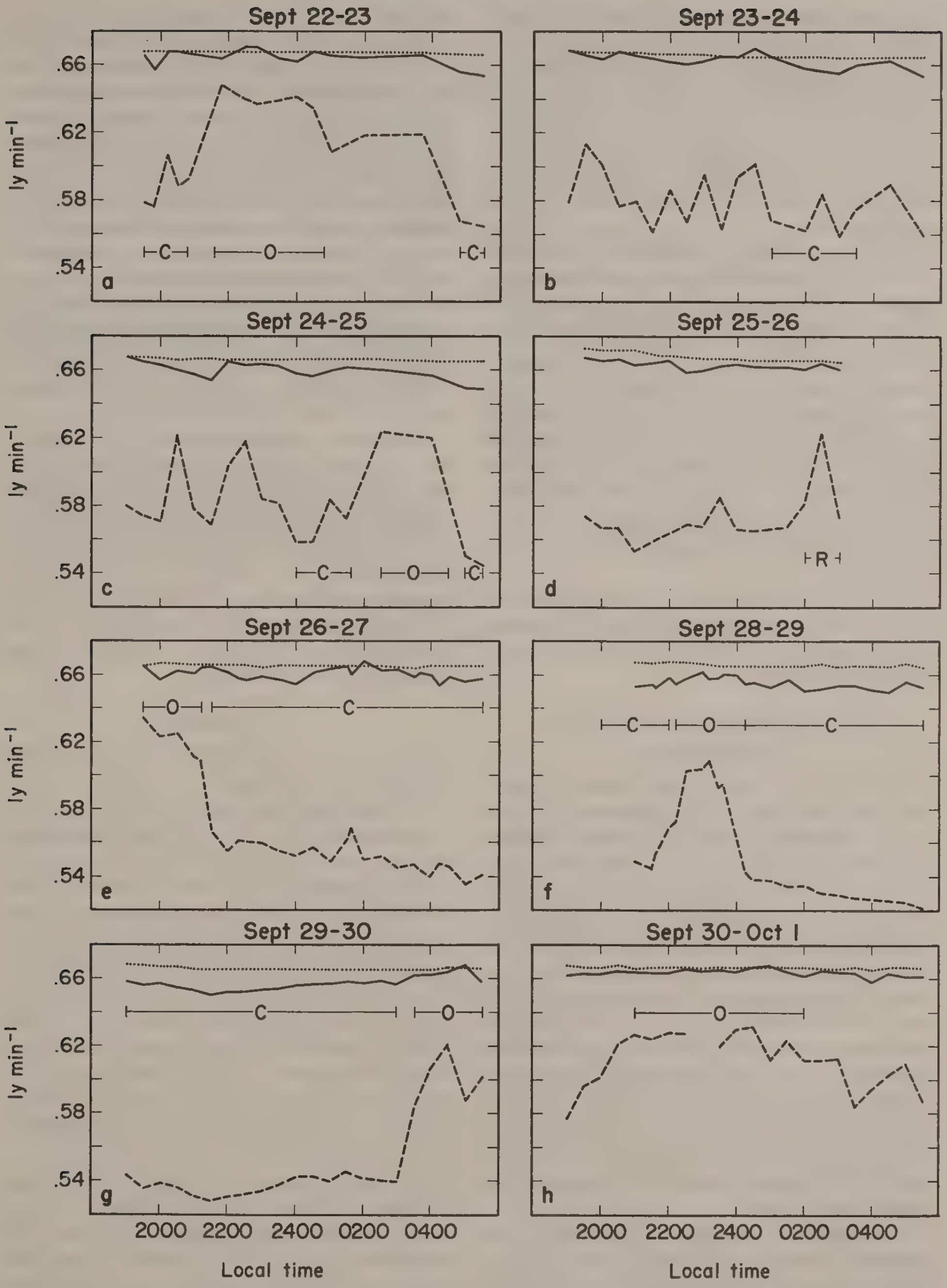


Fig. 2. Long-wave radiation off Barbers Point, Oahu, Hawaii, September 22 to October 1, 1965. R_w (solid line), radiation from the sea surface; R_s (broken line), radiation from the sky; σT_w^4 (dotted line), radiation calculated from surface water temperature. Overhead cloud cover variable or undefined except as noted: clear *C*, overcast *O*, rain *R*.

radiation changed from 0.57 ly min^{-1} to about 0.53 ly min^{-1}, a change nearly as large as that due to the cloud effect. Water temperature did not change appreciably. The variations in air temperature and vapor pressure each could cause only one-tenth of the observed changes. The other data describing the environment show no variation that could cause the observed change.

In this region it is possible that the height of the trade wind inversion can define the thickness of the humid air mass, which may be in part responsible for the change in sky radiation. A thicker air mass, due to the greater amount of water vapor in the column, may act much as a partial cloud cover and increase the sky radiation. The height of the trade wind inversion was not determined during the September series, but radiosonde data from other periods indicate variations in thickness of the tropical air mass of the order of 1000 m within a few days.

Continuous recording of the radiation, together with cloud observations and radiosonde measurements, would permit analysis of the observed variability.

NET LONG-WAVE RADIATION AT THE SEA SURFACE

The heat lost from the sea surface owing to net long-wave radiation is determined by taking the difference between the upward radiation from the sea surface and the downward radiation from the sky. In the Hawaiian region, this net radiation is small and is the difference between two large numbers. Errors or variations in the two radiation values are magnified in the value for net radiation. To obtain a more realistic and consistent value for net radiation, we used the mean values for sea and sky radiation. The mean values were obtained over periods of consistent environmental conditions which, for the September series, were from 3 to 6 hours. The resultant flux still represents the mean value that is consistent with the features of the physical environment.

Clear sky values obtained in this way during September ranged from 0.090 ly min^{-1} to about 0.120 ly min^{-1}, and values for the overcast condition ranged from less than 0.040 ly min^{-1} to more than 0.055 ly min^{-1}. All values, though small, indicated that net radiation was directed upward. Too few measurements were taken at one time during the March–June series to yield accurate mean values for the calculation of the flux. From Figure 1, estimates of mean values indicate net radiation values of the same order as the values for the September series, though the maximum values appear to be less than 0.10 ly min^{-1}. *Ekern* [1965] reported net radiation values at night over cane and pineapple fields on Oahu during the summer to average 0.11 ly min^{-1}, a value which is in the range, though on the high end, of those reported here. All values of radiation measured at sea during this project are in the same range as values obtained over land at about the same latitude, as reported by *Mani and Chacko* [1963].

These data may be compared with values of effective back radiation estimated from various empirical relationships based on surface temperature and relative humidity. *Laevastu* [1960] presented data which agree fairly well with the present data for a clear sky. The cloud factor formula that he suggested, however, gives values during overcast that are about half those presented here. These data indicate a cloud correction factor of about

$$1 - 0.06C \qquad (3)$$

where C is the cloud cover on a scale from 0 (clear sky) to 10 (overcast).

The net radiation computed from these observations indicates a total daily net radiation ranging from 58 to 173 ly day^{-1}. The values for climatic averages estimated by *Seckel* [1962] as 115 to 150 ly day^{-1} for the Hawaiian region fall within this range. From data (unpublished) on insolation taken on cruises during the Trade Wind Zone Oceanography Pilot Study, the value for total incoming radiation for a comparable period of the year ranges from 200 ly day^{-1} for overcast to 550 ly day^{-1} for a clear sky. Thus the net back radiation from the sea is equal to about 30% of the total radiation from the sky incident on the sea surface.

The results presented in this paper are based on data obtained to verify estimates of long-wave radiation from empirical formulas. This verification was partially attained. Also, these results point to a number of problems that should be investigated in detail for a full understanding of the heat exchange, through long-wave radiation, across the ocean-atmosphere interface. These problems include those concerned with the existence of the cool or warm 'skin' at the sea surface under natural conditions and its effect on the long-wave radiation from the sea, the effect of the water vapor content in the air column above the sensor on the long-wave radiation from the sky, the effects of the types of clouds and cloud cover, and the diurnal variability in the long-wave radiation at the sea surface.

Acknowledgments. I thank Gunter Seckel for contributions through criticism and encouragement and Colin Ramage and Paul C. Ekern for reviewing the initial manuscript and making suggestions.

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(Received May 7, 1966;
revised August 12, 1966.)

FURTHER COMMENTS ON SUPPRESSION OF SOME NAMES IN THE FAMILY BELONIDAE (PISCES). Z.N.(S.) 1723

(see volume 22, pages 325–329 and volume 23, pages 149–154)

By Bruce B. Collette (*Bureau of Commercial Fisheries Ichthyological Laboratory, Washington, D.C., U.S.A.*)

Additional comments are presented on several needlefish names that recently have been discussed in the *Bulletin* (Collette and Berry, 1966; Mees, 1966; Tortonese, 1967) and elsewhere (Mees, 1962, 1964; Collette and Berry, 1965) so that the Commission can have all the relevant material upon which to base its decision. Collette and Berry (1965) requested suppression of three names as *nomina oblita* under the provisions of Article 23 b. If action under the provisions of the 50-year rule is suspended, I believe it necessary to ask the Commission to suppress two names under the plenary powers. At least two of the names under discussion (*marina* and *crocodilus*) are of importance to parasitologists (working with copepods, trematodes, and cestodes) as well as to ichthyologists. The nomenclature of this family should be stabilized before completing manuscripts for an Atlantide Report (Collette and Parin, MS) and for " Fishes of the Western North Atlantic " (Collette MS). A summary of my opinions on the names for three species discussed by Collette and Berry (1966) and that for an additional species by Mees (1966) follows.

I. *Strongylura marina* (Walbaum)

Because it did not seem reasonable that a name totally unused for the 170 years after its description should replace the name usually used for the commonest species of western Atlantic needlefish, Collette and Berry (1966) applied to the Commission to suppress *houttuyni* in favour of *marina*, two names pertaining to the same species and described on the same page by Walbaum in 1792. The name *marina* is not only the name used by ichthyologists but is also the name used by parasitologists, for example by Linton in a series of papers on cestodes and trematodes from 1901 to 1940. Mees (1962) chose to ignore both provisions of Recommendation 24A—to " select the name that will best insure stability and universality of nomenclature " or, if neither name has this advantage, to " select the name that has precedence of position in the work in question ". In defence of his selection of *houttuyni* over *marina* as " first reviser ", Mees (1966) referred to the name *Esox timucu* Walbaum as another name commonly used in the western Atlantic and to the name *Belone senegalensis* Valenciennes, 1846 as being the name commonly used for *houttuyni* in the eastern Atlantic. Both the eastern Atlantic *S. senegalensis* and the Caribbean species known as *S. timucu* are valid species. *S. marina* has only the right gonad developed while both *S. senegalensis* and *S. timucu* have the usual pair of gonads. The three species also differ in other characters, such as the number of predorsal scales (Collette and Parin, MS): 110–130, mean 122 in *S. senegalensis*; 129–185, mean 156 in *S. timucu*; and 213–304, mean 255 in *S. marina*.

II. *Platybelone argalus* (LeSueur)

The three main points made by Collette and Berry (1965) were: (1) the name *argalus* LeSueur, 1821 is the earliest name for this particular species; (2) the figure in the original description is clearly this species and could not be any other species, and (3) after Fowler (1919 and 1930) pointed out its applicability to the species, the name *argalus* has appeared several times in the literature. This is true both in the western Atlantic (e.g., Fowler, 1941; Berry and Rivas, 1962; Cervigón, 1966) and in the eastern Atlantic (e.g. Fowler, 1963; Postel, 1959; 1960; Blache, 1962). In addition, Parin (1967) has recently used *argalus* in the western Pacific and Indian oceans. Mees (1962, 1966) considered *argalus* to be a composite partly because the fin ray counts of D 16, A 19 given in the original description are rather high; however, I have examined two specimens with these counts. The problem involving the name *argalus* is thus a biological one; Mees considers the name a composite and I believe it is applicable to the species in question. Therefore the Commission should leave the question of which name to use for this species to ichthyologists.

III. *Tylosurus crocodilus* (Peron and LeSueur)

Collette and Berry (1966) applied to the Commission to suppress *Esox belone* Var. *Maris rubri* Bloch and Schneider, 1801 because this name had not been used in the more than 160 years after its original description (except for a mention of it by Valenciennes in 1846 in his account of *Belone crocodilus* in Histoire Naturelle des Poissons). The use of *Belona crocodila* Peron and LeSueur, 1821 was recommended because it is the next oldest available name and it has had extensive use in the literature. Mees (1962 : 45) wrote that " This does not mean, however, that I agree with Weber + de Beaufort and with *all other modern authors*, that now *Belone crocodila* LeSueur (1821) becomes the oldest name available for the species . . . " (emphasis added). Not only has the name *crocodila* had wide usage in the Indo-Pacific, as Collette and Berry (1965, 1966) previously noted, but it also has had wide usage in the eastern Atlantic in the last 30 years (e.g., Fowler, 1936; Poll, 1953; Cadenat, 1950, 1960; Collignon, Rossignol, and Roux, 1957; Postel, 1959, 1960; Blache, 1962). The name *crocodila* also has been used by parasitologists, for example by Capart (1953, 1959) and Delamare-Deboutteville and Nunes-Ruivo (1954) in the Atlantic and by Pillai (1961) in the Indian Ocean for parasitic copepods. I agree with Mees (1964) that subsequent workers have ignored names such as *maris rubri* because they were originally introduced as applying to varieties rather than to species and I believe that this lends further weight to the desirability of rejecting *maris rubri*. Furthermore, Parin (1967) has just shown that two species are involved under Mees' *Belone maris rubri*—*T. crocodilus* and *T. choram* (Rüppell).

IV. *Tylosurus acus* (Lacépède)

The two reasons Collette and Berry (1966) gave for advocating the use of the name *Sphyraena acus* Lacépède, 1803, for the Atlantic species of *Tylosurus* with a long snout and a high number of dorsal and anal fin rays and vertebrae were: (1) it is the earliest name applicable to the species; and (2) it is the name most often used in the western Atlantic. Mees (1966) pointed out that the trivial name *acus* has been used for two different species of needlefishes in the eastern Atlantic: *Belone acus*

Risso, 1826 (a junior synonym of *Esox belone* Linnaeus) and *Sphyraena acus* Lacépède, 1803. Mees stated that the use of *acus* Lacépède would lead to confusion in the European literature. This confusion only would result if other workers accept Mees' lumping of *Strongylura*, *Tylosurus*, and five other genera that I consider valid with *Belone* (compare Mees, 1962, 1964 with Collette and Berry, 1965 and with Collette, 1966). The name *acus* Lacépède has frequently been used for this species of *Tylosurus* (sometimes as *Strongylura*) in the eastern Atlantic (e.g., Regan, 1911; Fowler, 1936; Tortonese, 1938; Lozano Rey, 1947; Ben-Tuvia, 1953; Postel, 1959, 1960; Blache, 1962) and recently by Parin (1967) in the western Pacific and Indian oceans. Moreover, *acus* Risso, 1826 was permanently taken out of consideration when it was replaced by *gracilis* Lowe, 1839. Mees (1966) further argued for *imperialis* Rafinesque, 1810 by referring to Lozano Rey (1947 : 603) who gave the Spanish vernacular name as ajuja imperial but Mees neglected to mention that Lozano Rey used *Strongylura acus* as the scientific name of the species and listed *imperialis* as a junior synonym. I believe the Commission should follow the law of priority in this case and reject Mees' request.

In conclusion, I believe the International Commission should reject previous requests on needlefish names except as follows:

(1) to use its plenary powers to suppress for the purposes of priority but not for those of homonymy the following names:
  (a) *Maris rubri* Bloch and Schneider, 1801, as published in the trinomen *Esox belone* Var. *Maris rubri*;
  (b) *houttuyni* Walbaum, 1792, as published in the binomen *Esox Houttuyni*;

(2) to place the following names on the Official List of Specific Names in Zoology:
  (a) *marina* Walbaum, 1792, as published in the binomen *Esox marinus*;
  (b) *crocodila* Peron and LeSueur in LeSueur, 1821, as published in the binomen *Belona crocodila*;

(3) to place the following names on the Index of Rejected and Invalid Specific Names in Zoology:
  (a) *Maris rubri* Bloch and Schneider, 1801, as suppressed under (1) (a);
  (b) *Houttuyni* Walbaum, 1792, as suppressed under (1) (b).

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Made in United States of America
Reprinted from Copeia, 1967, No. 4, December 8
pp. 814–819

The Taxonomic History of the Darters (Percidae: Etheostomatini)

Bruce B. Collette

The Taxonomic History of the Darters (Percidae: Etheostomatini)

BRUCE B. COLLETTE

The number of nominal species and subspecies described per year are compared with the cumulative summary of the number of forms considered valid. The history of darter descriptions is divided into four periods: "Beginnings" (1818–1840); "Golden Era" (1841–1892); "Doldrums" (1893–1931); and "Reawakening" (1932–present). The success of different ichthyologists in describing valid taxa is assessed. The number of specimens per type-series forms a strongly skewed distribution from 42 species based on only the holotype to the 1338 type-specimens of *Boleosoma nigrum eulepis.* The 25 repositories of the 4863 type-specimens of 185 nominal species of darters are divided into three groups based on the number of primary and secondary types. The present number of valid species and subspecies (139) is predicted to rise to about 160 by the year 2000.

INTRODUCTION

THE darters are a tribe of three genera of small North American freshwater fishes of the family Percidae (see inset, Fig. 2 for a representative darter). Some 215 additional nominal species and subspecies have been described since Constantine Rafinesque described *Sciaena caprodes* in his "Discoveries in natural history, made during a journey through the western region of the United States" published in 1818 in the "American Monthly Magazine and Critical Review." Approximately 139 of these appear to be valid taxa distinguishable at the specific or subspecific level and more than a dozen forms are known that await description. This paper is an analysis and summary of the data resulting from the preparation of a catalogue of the type-specimens of the darters (Collette and Knapp, 1967) and is presented as a survey of the taxonomic history of a moderately large group of species.

HISTORY

The number of nominal species of darters described per year is presented in Fig. 1. A cumulative summary of the number of forms currently considered valid is also plotted on the same figure for comparison with the peaks caused by large numbers of original descriptions in a given year. The correlation of a peak in descriptions with a sharp upward turn of the cumulative line indicates competent taxonomists at work. Some of the more prominent peaks are labeled.

The history of darter descriptions is arbitrarily divided into four periods: "Beginnings" (1818–1840); "Golden Era" (1841–1892); "Doldrums" (1893–1931); and "Reawakening" (1932–present).

Rafinesque published three papers describing five species of darters (four valid) in 1818–1820—the only activity during the "Beginnings."

The "Golden Era" began in 1841–1845 with six papers by Jared P. Kirtland (Ohio); James E. DeKay (New York); Samuel S. Haldeman (Pennsylvania); and D. H. Storer (Illinois, Alabama, Connecticut). Then followed the first attempt at synthesis and a peak of descriptions of new species in Louis Agassiz's works of 1850 and 1854. He described nine species of which six are valid. Charles Girard described the most darters in a single paper—17 species—in 1859, mostly from "Railroad and Boundary Survey" specimens. Of the 20 species Girard and Spencer F. Baird described, 14 are presently considered valid. Edward Drinker Cope described 18 darters in several papers published between 1864 and 1880, of which 11 are considered valid.

David Starr Jordan published his first darter description in 1877. He and his coworkers described a total of 41 forms of which 29 are considered valid. His student Charles H. Gilbert, alone or with other workers, described 14 darters of which 11 are valid. Most of these species were described in Gilbert (1887).

After 1892 the number of darter descriptions became fewer as did the number of

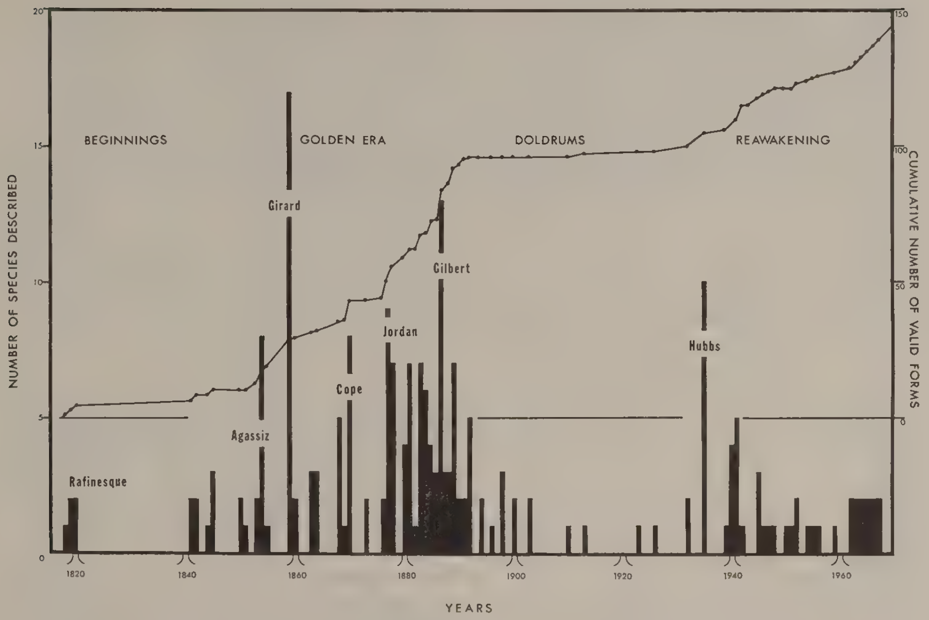

Fig. 1. Number of species of darters described per year (bars, scale on left axis) and cumulative number of valid forms (line and dots, scale on right axis). Names of several prominent darter describers are placed on the year of their major publication.

valid forms described. About 62% of the 147 darters described during the half century "Golden Era" have proved to be valid. Only two of the 13 forms described during the "Doldrums" of 1893–1931 are presently recognized. The poor quality and quantity of work on darters at that time is largely due to the apparent completeness and magnitude of Jordan and Evermann's classic "Fishes of North and Middle America." After publication of this work, Jordan and his students turned their attention away from North American fishes (Hubbs, 1964).

Carl L. Hubbs initiated the "Reawakening" with his description of *Poecilichthys osburni* with Milton B. Trautman in 1932. Hubbs' 1935 paper with Mott D. Cannon on the darters of the genera *Hololepis* and *Villora* included nine new species and subspecies for the third highest peak in Fig. 1. In 1940 and 1941 Hubbs and John D. Black described five more forms. Hubbs and his co-workers described a total of 19 species and subspecies between 1934 and 1954, of which 14 are still recognized. Reeve M. Bailey and Edward C. Raney began to describe darters in 1940–1941, and they and their students have continued to keep the cumulative number of valid darters rising at a steady rate. The three most recent descriptions of new species of darters—*Etheostoma* (*Nothonotus*) *rubrum* Raney and Suttkus, 1966; *E.* (*N.*) *microlepidum* Raney and Zorach, 1967; and *Percina* (*Hadropterus*) *aurolineata* Suttkus and Ramsey, 1967—appeared after completion of the type catalogue but are included in the present analysis.

Darter describers may be divided into three categories: Division I—those who described nine or more species; Division II—those who described three to six species; and Division III—those who described one or two species. Table 1 summarizes the number of forms described by each worker or group of workers and the fate of these forms for the first two divisions. Workers in Division III are combined into two groups based on whether they described one or two new species.

In Division I Gilbert was the best darter describer in terms of adequacy of descrip-

Table 1. Comparison of the Number of Nominal Species of Darters Described by Various Workers with the Number of Forms Currently Considered Valid.

Describer	No. Described	No. Valid	% Valid
Division I (9 or more species)			
Gilbert *et al.*	14	11	79
Hubbs *et al.*	19	14	74
Jordan *et al.*	41	29	71
Girard *et al.*	20	14	70
Agassiz	9	6	67
Cope *et al.*	18	11	61
Hay	11	5	45
Division II (3–6 species)			
Bailey *et al.*	5	5	100
Raney *et al.*	4	4	100
Moore *et al.*	3	3	100
Fowler	6	5	83
Rafinesque	5	4	80
Storer	4	3	75
Kirtland	3	2	67
Evermann *et al.*	6	0	0
Haldeman	3	0	0
Division III (1 or 2 species)			
20 authors	20	12	60
10 authors	20	11	55

tions and percentage of valid forms (79%). He is followed by Hubbs and his co-workers (74%) and by Jordan and his co-workers (71%). Oliver P. Hay rated lowest (45%) with his description of 11 darters.

The three groups of modern workers and their students in Division II, Reeve M. Bailey, George C. Moore, and Edward C. Raney, have a perfect score at the present time. Samuel S. Haldeman (three species, 1842–1844) and Barton W. Evermann (six species, 1894–1910) share the dubious distinction of having none of their species presently considered valid. Kirtland, Rafinesque, Fowler, and Storer were intermediate in success.

The 20 workers in Division III who described only one darter and the ten workers who described two species had average success—55–60% of their species remain valid.

Type-Specimens

Another topic worthy of consideration is the number of specimens per type-series (Fig. 2). No material is extant for any of Rafinque's five darters; five names are replacements for preoccupied names; and all type material is apparently lost for 21 nominal species. Thus, information is available for 185 nominal species. The frequency of specimens per type-series forms a strongly skewed distribution from 42 species based on only the holotype to the 1338 specimens that constitute the type-series of *Boleosoma nigrum eulepis* Hubbs and Greene, 1935. Nearly a quarter of the nominal species were based on only the holotype, more than a third on the holotype plus one paratype, and more than half of four on fewer type-specimens.

The distribution of the 4863 type-specimens among 25 institutions is summarized in Table 2. As in the analysis of number of specimens per type-series, data are available for the type-specimens of 185 nominal spe-

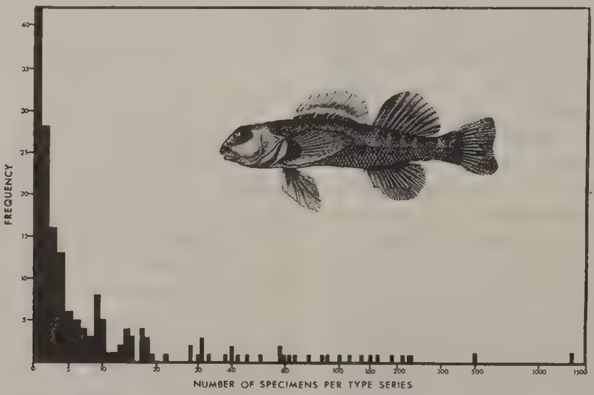

Fig. 2. Semi-logarithmic plot of the frequency of type-specimens per type-series of the nominal species of darters. Inset: drawing of a male *Etheostoma variatum* Kirtland in breeding condition.

Table 2. Holdings of Type-specimens of Nominal Species of Darters in Museums. Secondary types not counted in institutions also having the primary type of a given species. Abbreviations of museums in text.

	Holotypes	Lectotypes	Syntypes	Total Primary Types	Paralectotypes	Paratypes	Total Secondary Types	Total
Group I—Many primary and secondary type-specimens								
USNM	33	50	13	96	3	29	32	128
UMMZ	28	1	8	37	16	9	25	62
ANSP	13	11	1	25	0	1	1	26
MCZ	6	6	9	21	13	4	17	38
Group II—Few primary but many secondary type-specimens								
SU	0	1	6	7	11	6	17	24
CU	6	0	0	6	1	7	8	14
BMNH	1	1	1	3	5	0	5	8
MNHN	1	1	1	3	1	0	1	4
TU	2	0	0	2	0	5	5	7
KU	1	0	0	1	0	1	1	2
INHS	1	0	0	1	0	0	0	1
Group III—Few secondary types								
OSU	–	–	–	–	–	4	4	4
DU	–	–	–	–	–	3	3	3
UOMZ	–	–	–	–	–	2	2	2
CAS	–	–	–	–	2	–	2	2
CM	–	–	–	–	–	2	2	2
FMNH	–	–	–	–	–	2	2	2
UAIC	–	–	–	–	–	2	2	2
FSU	–	–	–	–	–	1	1	1
OSM	–	–	–	–	–	1	1	1
TAMC	–	–	–	–	–	1	1	1
TNHC	–	–	–	–	–	1	1	1
UR	–	–	–	–	–	1	1	1
UW	–	–	–	–	–	1	1	1
VPI	–	–	–	–	–	1	1	1

cies. The repositories fall into three groups: Group I—large numbers of primary and secondary types; Group II—few primary types but significant holdings of secondary types; and Group III—no primary types and only a few paratypes. Group I is clearly due to the efforts of the workers in Divisions I and II. Jordan, Gilbert, Hay, and Evermann placed most of their types in the U. S. National Museum (USNM). The types of 16 Girard species were originally deposited in the USNM and were loaned to the Museum of Comparative Zoology (MCZ) in about 1860 for Frederick Putnam to study (Collette and Knapp, 1967, table 1). They were then catalogued twice at the MCZ. These types plus the types of species described by Agassiz and by Putnam place the MCZ in Group I. Later, specimens from many of the MCZ darter type-series were transferred to the University of Michigan (UMMZ) by Carl L. Hubbs. Hubbs, Bailey, Raney, and Moore deposited most of their primary type-specimens of darters in the UMMZ. Types of some of Jordan's species were transferred from Indiana University to the California Academy of Sciences and then to UMMZ. Cope and Fowler are the main sources of darter types at the Academy of Natural Sciences of Philadelphia.

In Group II, Stanford University leads due to a series of syntypes of Jordan's species. Cornell University has a moderate number of secondary types but is low in primary types because several of these were deposited at UMMZ or USNM. The British Museum (Nat. Hist.) is in Group II because of early exchanges with USNM. The Paris Museum

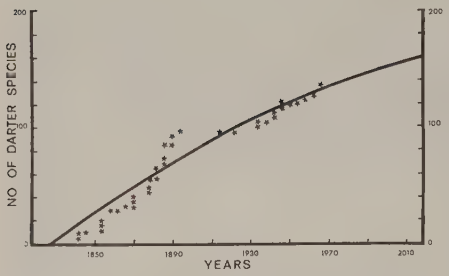

Fig. 3. Second degree polynomial curve of cumulative number of valid forms of darters extrapolated to the year 2010.

received material from Cope and from Agassiz for Vaillant's 1873 monograph of the darters.

Group III consists mainly of universities which have retained paratypes of species based partially on their material but have placed most of their holotypes in UMMZ or USNM.

CONCLUSIONS

If the second degree polynomial curve of the cumulative number of valid forms is extrapolated (Fig. 3), it can be predicted that there will be about 160 valid species and subspecies described by the year 2000. This seems to be a reasonable estimate because there are at least a dozen undescribed forms known to exist at the present (especially in the subgenera *Ulocentra* and *Oligocephalus* of *Etheostoma*).

Future darter describers should consider depositing their primary types either at USNM or at UMMZ because of their large holdings of darter types, their stability, and the fresh comparative material available. Paratypes of new darters should be placed in the other museums in Group I as well as in selected institutions in Group II.

This analysis is somewhat similar in approach to the papers by Barnard (1958) on marine amphipods and by Reish (1958) on polychaetous annelids but is limited to a smaller group of animals. Barnard found similar fluctuations in the number of species described but the curve of cumulative valid species had no period of leveling off like the darter "Doldrums." Reish found a significant decline in papers published during World Wars I and II that is not apparent in the darters.

Abbreviations of the 25 collections housing darter types are as follows: ANSP: Academy of Natural Sciences, Philadelphia; BMNH: British Museum (Natural History), London; CM: Charleston Museum, Charleston, South Carolina; CU: Cornell University, Ithaca, New York; DU: Duke University, Durham, North Carolina; FMNH: Field Museum of Natural History, Chicago; FSU: Florida State University, Tallahassee; INHS: Illinois Natural History Survey, Urbana; KU: Kansas University, Lawrence; MCZ: Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts; MNHN: Muséum National d'Histoire Naturelle, Paris; OSU: Oklahoma State University, Stillwater; OSM: Ohio State Museum, Columbus; SU: Stanford University, Division of Systematic Biology, Stanford, California; TAMC: Texas Agricultural and Mechanical University, College Station; TNHC: Texas Natural History Collections, University of Texas, Austin; TU: Tulane University, New Orleans, Louisiana; UAIC: University of Alabama Ichthyological Collections, University, Alabama; UMMZ: University of Michigan Museum of Zoology, Ann Arbor; UOMZ: University of Oklahoma Museum of Zoology, Norman; UR: University of Richmond, Richmond, Virginia; USNM: U. S. National Museum, Washington, D. C.; UW: University of Wisconsin, Milwaukee; VPI: Virginia Polytechnic Institute, Blacksburg, Virginia.

ACKNOWLEDGMENTS

Leslie W. Knapp reviewed drafts of this manuscript and participated in the involved work of preparing the type catalogue. The members of the "Poets Club" at the U. S. National Museum have offered comments and encouragement.

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Proceedings of
the United States
National Museum

SMITHSONIAN INSTITUTION • WASHINGTON, D.C.

Volume 119 | 1966 | Number 3550

CATALOG OF TYPE SPECIMENS OF THE DARTERS (PISCES, PERCIDAE, ETHEOSTOMATINI)[1]

By **Bruce B. Collette** and **Leslie W. Knapp**[2]

Introduction

The darters are a tribe of small freshwater fishes restricted to North America. Some 212 specific and subspecific names have been proposed for the approximately 100 valid described species. About a dozen species await description. As part of a long-term study of these fishes, we have prepared this catalog of type specimens. We hope that our efforts will be of value in furthering systematic research and stabilizing the nomenclature of this most fascinating group of North American fishes.

In preparing this catalog we have attempted to examine or at least to verify the location of the type specimens of all nominal forms of the three presently recognized genera of darters: *Percina*, *Ammocrypta*, and *Etheostoma*. By type specimens we mean holotypes, lectotypes, syntypes, paralectotypes, and paratypes. Each form is listed in alphabetical order by the generic and specific name used in the original description. If subgeneric allocation was made in the original description, that name has been placed in parentheses between the genus and the species. Holotypes or lectotypes are listed before paratypes or paralectotypes.

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[1] Fifth paper in a series on the systematics of the Percidae by the senior author.

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The following data appear after each name: (1) citation of original description; (2) catalog number; (3) number of specimens and range in standard length in mm. are in parentheses; sex is given in a few cases; (4) locality; (5) collector; (6) date of collection; (7) determination of current status with reference to pertinent literature.

All original descriptions were consulted to help determine whether a collection was actually type material. The generic and subgeneric arrangement is modified from that presented by Bailey (*in* Bailey, Winn, and Smith, 1954, and *in* Bailey and Gosline, 1955). The use of the tribe Etheostomatini for the darters follows Collette (1963).

Lectotypes were selected in some instances in order to stabilize nomenclature. The following people have assisted in the selection of lectotypes: Dr. Charles F. Cole (subgenus *Boleosoma*); Mr. Donald A. Distler (*E. spectabile*); Dr. Robert V. Miller (*E. blennioides*); Dr. Edward C. Raney (*P. notogramma, P. crassa,* subgenus *Nothonotus*); Dr. William J. Richards (*E. swannanoa, E. thalassinum*); Dr. Chu-fa Tsai (*E. histrio, E. rupestre,* and *E. zonale*). Brief data are presented for each lectotype herein selected and the following abbreviations are used: D=dorsal spines (Roman numerals) and rays (Arabic numerals); A=anal spines (Roman) and rays (Arabic); LL=number of lateral line scales; POM=number of preoperculomandibular pores; and INF=number of infraorbital pores. If the lateral line is incomplete, the number of pored scales is given first, separated from the number of unpored scales by a plus sign; if the infraorbital canal is incomplete, the number of pores in the anterior portion is separated from the number in the posterior portion by a plus sign.

Five nominal species are replacement names. No original material was saved of the five species of darters described by Constantine Rafinesque. Type material of 21 nominal species could not be located. In instances where a type series was divided among several institutions, we usually located some of the specimens. However, when all of the types of a form were deposited in one institution we were occasionally unable to locate any specimens.

About 1860, a considerable number of darters, including types of 16 species described by Charles Girard, were sent from the U.S. National Museum to the Museum of Comparative Zoology at Harvard University for Frederick Putnam to study. Many of these were cataloged into the MCZ collection (table 1), and Jordan and others subsequently believed them lost. Representatives from a number of these series at the MCZ were later transferred to the University of Michigan Museum of Zoology by Carl L. Hubbs.

Another problem concerns the type material studied by Jordan at Indiana University. These specimens first received a lot number and later a regular catalog number. We have recorded both numbers. Some of these specimens are now at Stanford; many were transferred to the California Academy of Sciences. Later, some of the CAS types

Table 1.—*Darter types transferred from USNM to MCZ*

USNM No.	First MCZ No.	Present MCZ No.	Species and describer	Locality
740	269	24599	*Pileoma carbonaria* Baird and Girard.	Tex., Río Salado
743	87	24625	*Diplesion fasciatus* Girard	Mex., Chihuahua R.
744	82	24575	*Boleosoma lepida* Baird and Girard.	Tex., Río Leona
745	84	24567	*Boleichthys elegans* Girard	Tex., Piedrapainte
748	83	24580	*Oligocephalus leonensis* Girard	Tex., Río Leona
1157	130	24546	*Hadropterus maculatus* Girard	Md., Potomac R.
1175	257	24636	*Pileoma zebra* Agassiz	Lake Superior
1179	1179	1179	*Aplesion potsii* Girard	Mex., Chihuahua R.
1182	85	24576	*Oligocephalus grahami* Girard	Tex., Devil's R.
1187	22	24652	*Catonotus fasciatus* Girard	N.Y., Grass R.
1188	101	24589	*Boleosoma fusiforme* Girard	Mass., Charles R.
1192	87	24625	*Diplesion fasciatus* Girard	Mex., Chihuahua R.
1197	122	24603	*Hadropterus nigrofasciatus* Agassiz.	Ala., near Mobile
1203	16	24634	*Oligocephalus humeralis* Girard	Va., James R.
1203	16	35975	*Oligocephalus humeralis* Girard	Va., James R.
1206	87	24625	*Diplesion fasciatus* Girard	Mex., Chihuahua R.
1283	93	24570	*Microperca punctulata* Putnam	Wis., Oconomowoc R.
1288	94	24690	*Microperca punctulata* Putnam	Mich., Pt. Huron
1294	96	24582	*Microperca punctulata* Putnam	Mich., Detroit R.
1303	129	24525	*Hadropterus maculatus* Girard	Md., Potomac R.
1311	270	24616	*Pleurolepis pellucidus* Agassiz	Ohio, Black R.
1327	----	32952	*Boleichthys warreni* Girard	N. Dak., Cannon Ball R.
1328	113	113	*Boleosoma gracile* Girard	Tex., Río Seco
1333	41	24569	*Boleichthys whipplii* Girard	Okla., Coal Cr.
1334	----	32950	*Oligocephalus pulchellus* Girard	Okla., Gypsum Cr.
1336	114	24728	*Boleichthys exilis* Girard	N. Dak., Little Muddy R.
1365	2	24658	*Catonotus Kennicotti* Putnam	Ill., Union Co.
1377	95	24566	*Microperca punctulata* Putnam	Ill., Calumet R.
1393	21	24656	*Catonotus fasciatus* Girard	N.Y., Grass R.
1801	1	24637	*Catonotus lineolatus* Agassiz	Ill., near Quincy
1801	1	24657	*Catonotus lineolatus* Agassiz	Ill., near Quincy
1811	37	24665	*Catonotus Kennicotti* Putnam	Ill., Union Co.
1865	237	24602	*Hyostoma Newmanii* Agassiz	Ala., Huntsville

were transferred to the University of Michigan. However, a number are still missing.

In addition to listing the type specimens, we have compiled a list of the genus-group names proposed for the darters. The original description for each was verified. We have attempted to discover the first subsequent selection of type-species for those nominal genera which lacked originally designated type-species. The list is divided into available and unavailable genus-group names.

To facilitate using this catalog, we have also compiled an alphabetical index of nominal forms, using the original spelling. The author and the genus in which the species was originally described follow the specific name. Abbreviations of museums presently housing type material of each form are given following the name. Museums with the holotype, lectotype, or most syntypes are listed first. A museum abbreviation with a question mark indicates where the types were probably originally deposited even though we could not locate them. A question mark indicates we could not locate any types and do not know where they might be. An "X" is used when there was no type material, or it is almost certainly lost.

We express our deep appreciation to the curators and staffs of the museums and collections which house the type material of the darters. Type material is or has been in the collections listed below. Collections marked with an asterisk have been visited by one or both of the authors (BBC, LWK). Other initials represent those who kindly verified material in a few collections, with small holdings of darter types, which we were unable to visit.

*ANSP	Academy of Natural Sciences, Philadelphia. Dr. James E. Böhlke. [BBC, LWK.]
*BF	U.S. Bureau of Fisheries. Collection now merged with USNM.
*BMNH	British Museum (Natural History). Dr. P. H. Greenwood, Mr. Peter J. Whitehead. [BBC.]
*CAS	California Academy of Sciences, San Francisco. Mr. W. I. Follett, Mrs. Lillian Dempster. [BBC, LWK.]
*CM	Charleston Museum, S.C. Mr. E. Milby Burton. [BBC]
*CU	Cornell University, Ithaca, N.Y. Dr. Edward C. Raney, Mr. Timothy Zorach, Mr. Robert E. Jenkins. [BBC, LWK.]
*DU	Duke University, Durham, N.C. Dr. Joseph R. Bailey, Dr. Walter R. Courtenay, Jr. [BBC.]
*FMNH	Field Museum of Natural History, Chicago. Mrs. Marion Grey, Miss Pearl Sonoda. [BBC, LWK.]
*INHS	Illinois Natural History Survey, Urbana. Dr. Philip W. Smith [BBC, LWK.]
*ISC	Iowa State University, Ames. Dr. Kenneth D. Carlander. Type darters transferred to USNM. [BBC.]
*IU	Indiana University, Bloomington. Specimens now at CAS or UMMZ. [BBC, LWK.]
*KU	Kansas University, Lawrence. Dr. Frank B. Cross. [LWK, BBC].

*MCZ	Museum of Comparative Zoology, Harvard. Dr. Giles W. Mead, Mrs. Myvanwy Dick. [BBC, LWK.]
*MNHN	Muséum National d'Histoire Naturelle, Paris. Mme. M. L. Bauchot. [LWK, BBC.]
*NCSM	North Carolina State Museum, Raleigh. Mr. William M. Palmer. Darter types transferred to USNM. [BBC, LWK.]
OAM–OSU	Oklahoma Agricultural and Mechanical College, now Oklahoma State University, Stillwater. Dr. Rudolph J. Miller. [RJM.]
*OSM	Ohio State Museum, Columbus. Dr. Milton B. Trautman. [BBC, LWK.]
*SU	Stanford University, Division of Systematic Biology. Dr. George S. Myers, Dr. Warren C. Freihofer, Mr. Stewart Springer. [BBC, LWK.]
TAMC	Texas Agricultural and Mechanical University, College Station. Dr. Richard J. Baldauf. [RJB.]
TNHC	Texas Natural History Collections, University of Texas, Austin. Dr. Clark Hubbs. [CH.]
TU	Tulane University, New Orleans. Dr. Royal D. Suttkus, Dr. John S. Ramsey. [JSR.]
*TUC	Tulsa University Collections. Dr. Albert P. Blair. Darter types transferred to USNM. [BBC.]
UAIC	University of Alabama Ichthyological Collections. Mr. William M. Howell. [WMH.]
UG	University of Georgia, Athens. Dr. Donald C. Scott. Darter types transferred to CU. [Dr. William Richards, LWK.]
*UMMZ	University of Michigan, Museum of Zoology, Ann Arbor. Dr. Reeve M. Bailey, Dr. Robert R. Miller. [BBC, LWK.]
UOMZ	University of Oklahoma, Museum of Zoology, Norman. Dr. Carl D. Riggs. [CDR.]
UR	University of Richmond, Richmond, Va. Dr. William S. Woolcott. [WSW.]
*USNM	U.S. National Museum, Washington. [BBC, LWK.]
UW	University of Wisconsin, Milwaukee. Dr. Carroll R. Norden. [CRN.]
VPI	Virginia Polytechnic Institute, Blacksburg. Dr. William S. Woolcott. [WSW.]

In addition to those already mentioned who have selected lectotypes or who have permitted us to examine material housed in their institutions, we wish to thank Drs. Robert H. Gibbs, Jr., James A. Peters, and W. Ralph Taylor of the U.S. National Museum, for critically commenting upon the manuscript.

Available Genus-Group Names

Allohistium Bailey *in* Bailey and Gosline, 1955, Misc. Publ. Mus. Zool. Univ. Michigan, no. 93, p. 6. Type-species *Etheostoma cinerea* Storer, 1845, by original designation.

Alvordius Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 68. Type-species *Alvordius maculatus* Girard, 1859, by monotypy.

Ammocrypta Jordan, 1877, U.S. Nat. Mus. Bull. 10, p. 5. Type-species *Ammocrypta beanii* Jordan, 1877, by original designation.

Anemoces Jordan, 1929, Manual of Vertebrates, 13th ed., p. 156. Type-species *Ulocentra gilberti* Evermann and Thoburn *in* Jordan and Evermann, 1896, by original designation.

Arlina Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 64. Type-species *Arlina effulgens* Girard, 1859 (=*Etheostoma olmstedi* Storer, 1842), by monotypy.

Asproperca Heckel *in* Canestrini, 1860, Verh. Zool.-Bot. Wien, vol. 10, p. 311. Type-species "*Asproperca zebra* Heck." (=*Pileoma zebra* Agassiz, 1850), by monotypy.

Astatichthys Vaillant, 1873, Nouv. Arch. Mus. Hist. Nat. Paris, vol. 9, p. 106. Type-species *Etheostoma caeruleum* Storer, 1845, by original designation.

Austroperca Hubbs, 1936, Occ. Pap. Mus. Zool. Univ. Michigan, no. 341, p. 1. A replacement name for *Torrentaria* Jordan and Evermann, 1896, preoccupied by *Torrentaria* (Hodgson MS) Gray, 1863, Aves. Takes the same type-species as *Torrentaria* Jordan and Evermann, *Etheostoma australe* Jordan, 1884.

Belophlox Fowler, 1947, Not. Nat. Acad. Nat. Sci. Philadelphia, no. 191, p. 1. Type-species *Belophlox mariae* Fowler, 1947, by original designation.

Boleichthys Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 103. Type-species *Boleichthys exilis* Girard, 1859, by original designation.

Boleosoma DeKay, 1842, Nat. Hist. New York Zool., vol. 4, p. 20. Type-species *Boleosoma tessellatum* DeKay, 1842 (=*Etheostoma olmstedi* Storer), by monotypy.

Catonotus Agassiz, 1854, Amer. Journ. Sci. and Arts, vol. 17, p. 305. Type-species *Catonotus lineolatus* Agassiz, 1854 (=*Etheostoma flabellaris* Rafinesque, 1819), by monotypy.

Claricola Jordan and Evermann, 1896, U.S. Nat. Mus. Bull. 47, p. 1093. Type-species *Etheostoma juliae* Meek, 1891, by original designation.

Copelandellus Jordan and Evermann, 1896, U.S. Nat. Mus. Bull. 47, p. 1100. Type-species *Poecilichthys quiescens* Jordan, 1884 (= *Boleosoma fusiforme* Girard, 1854), by original designation.

Cottogaster Putnam, 1863, Bull. Mus. Comp. Zool., vol. 1, p. 4 Type-species *Boleosoma tessellatum* Thompson, 1853, not of DeKay (= *Rheocrypta copelandi* Jordan, 1877), by monotypy.

Crystallaria Jordan and Gilbert *in* Jordan 1885, Ann. Rep. Comm. Fish and Fish. for 1885, p. 866. Type-species *Pleurolepis asprellus* Jordan, 1878, by original designation.

Diplesion Rafinesque, 1820, Ichthyologia Ohiensis, p. 37. Type-species *Etheostoma blennioides* Rafinesque, 1819, by subsequent designation of Girard, 1859, p. 101 and Jordan and Gilbert, 1877, p. 86.

Doration Jordan, 1929, Manual of the Vertebrates, 13th ed., p. 156. Type-species *Boleosoma stigmaeum* Jordan, 1877, by original designation.

Ericosma Jordan, 1877, U.S. Nat. Mus. Bull. 10, p. 8. Type-species *Alvordius evides* Jordan and Copeland, 1877, by original designation.

Estrella Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 65. Type-species *Estrella atromaculata* Girard, 1859 (=*Etheostoma olmstedi* Storer, 1842), by monotypy.

Etheostoma Rafinesque, 1819, Journ. Phys., Chim., Hist. Nat., vol. 88, p. 419. Type-species *Etheostoma blennioides* Rafinesque, 1819, by subsequent designation of Agassiz (1854, p. 305). Verified by Opinion 14, Int. Comm. Zool. Nomen., 1910, Smithsonian Inst. Publ., 1938, pp. 25–27. Not *Etheostoma flabellaris* Rafinesque, 1819, as designated by Jordan and Gilbert, 1877, p. 85.

Hadropterus Agassiz, 1854, Amer. Journ. Sci. and Arts, vol. 17, p. 305. Type-species *Hadropterus nigrofasciatus* Agassiz, 1854, by monotypy.

Hololepis Agassiz *in* Putnam, 1863. Bull. Mus. Comp. Zool., vol. 1, p. 4. Type-species *Boleosoma Barratti* Holbrook, 1885 (=*Boleosoma fusiforme* Girard, 1854), by subsequent designation of Jordan and Gilbert, 1877, p. 93.

Hyostoma Agassiz, 1854, Amer. Journ. Sci. and Arts, vol. 17, p. 305. Type-species *Hyostoma Newmanii* Agassiz, 1854 (=*Etheostoma blennioides* Rafinesque, 1819), by monotypy.

Hypohomus Cope, 1870, Proc. Amer. Philos. Soc., vol. 11, p. 449. Type-species *Cottogaster aurantiacus* Cope, 1869, by monotypy.

Imostoma Jordan, 1877, Proc. Acad. Nat. Sci. Philadelphia, vol. 29, p. 49. Type-species *Hadropterus shumardi* Girard, 1859, by original designation.

Ioa Jordan and Brayton, 1878, U.S. Nat. Mus. Bull. 12, p. 88. Type-species *Poecilichthys vitreus* Cope, 1870, by original designation.

Litocara Bailey, 1948, Copeia, 1948, p. 79. Type-species *Poecilichthys sagitta* Jordan and Swain, 1883, by original designation.

Microperca Putnam, 1863, Bull. Mus. Comp. Zool., vol. 1, p. 4. Type-species *Microperca punctulata* Putnam, 1863 (=*Etheostoma microperca* Jordan and Gilbert, *in* Jordan 1888), by monotypy.

Nanostoma Putnam *in* Jordan, 1877, U.S. Nat. Mus. Bull. 10, p. 6. Type-species *Poecilichthys zonalis* Cope, 1868, by original designation.

Niviperca Whitley, 1951, Proc. Royal Zool. Soc. New South Wales, 1949–50, p. 68. A replacement name for *Nivicola* Jordan and Evermann preoccupied by *Nivicola* Hodgson, 1844, Aves. Takes the same type-species as *Nivicola* Jordan and Evermann, *Poecilichthys borealis* Jordan, 1844 (=*Boleichthys exilis* Girard, 1859).

Nothonotus Agassiz *in* Putnam, 1863, Bull. Mus. Comp. Zool., vol. 1, p. 3. Type-species *Etheostoma maculatum* Kirtland, 1840, by subsequent designation of Jordan and Gilbert 1877, p. 93.

Oligocephalus Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 67. Type-species *Boleosoma lepida* Baird and Girard, 1853, by subsequent designation of Vaillant (1873, p. 90).

Percina Haldeman, 1842, Journ. Acad. Nat. Sci. Philadelphia, vol. 8, p. 330. Type-species *Perca nebulosa* Haldeman, 1842 (=*Sciaena caprodes* Rafinesque, 1818), by monotypy.

Pileoma DeKay, 1842, Nat. Hist. New York Zool., vol. 1, pt. 4, p. 16. Type-species *Pileoma semifasciata* DeKay, 1842 (=*Sciaena caprodes* Rafinesque, 1818), by monotypy.

Plesioperca Vaillant, 1873, Nouv. Arch. Mus. Hist. Nat. Paris, vol. 9, p. 36. Type-species *Plesioperca anceps* Vaillant, 1873 (=*Hadropterus nigrofasciatus* Agassiz, 1854), by monotypy.

Poecilichthys Agassiz, 1854, Amer. Journ. Sci. and Arts, vol. 7, p. 304. A replacement name for *Poecilosoma* Agassiz, 1850, preoccupied by *Poecilosoma* Huebner, 1819, Lepidoptera; *Poecilosoma* Stephens 1829, Hemiptera; *Poecilosoma* Newman, 1838, Coleoptera. Takes the same type-species as *Poecilosoma* Agassiz, *Etheostoma variatum* Kirtland, 1838.

Psychromaster Jordan and Evermann, 1896, U.S. Nat. Mus. Bull. 47, p. 1099. Type-species *Etheostoma tuscumbia* Gilbert and Swain, 1887, by original designation.

Rafinesquiellus Jordan and Evermann, 1896, U.S. Nat. Mus. Bull. 47, p. 1082. Type-species *Aplesion pottsii* Girard 1859, by original designation.

Rheocrypta Jordan, 1877, U.S. Nat. Mus. Bull. 10, p. 9. Type-species *Rheocrypta copelandi* Jordan, 1877, by monotypy.

Rhothoeca Jordan, 1885, Ann. Rept. Comm. Fish and Fish. for 1885, p. 868. Substitute name for *Nanostoma* Putnam erroneously regarded as preoccupied by *Nannostomus* Günther and taking the same type-species *Poecilichthys zonalis* Cope, 1869.

Richiella Coker, 1927, Copeia, no. 162, p. 18. Substitute name for *Richia* Coker preoccupied by *Richia* Grote, 1887, Lepidoptera. Takes the same type-species as *Richia* Coker, *Richia brevispina* Coker, 1926 (=*Etheostoma flabellaris* Rafinesque, 1819).

Serraria Gilbert, 1884, Proc. U.S. Nat. Mus. vol. 7, p. 205. Type-species *Hadropterus scierus* Swain, 1883, by original designation.

Swainia Jordan and Evermann, 1896, U.S. Nat. Mus. Bull. 47, p. 1040. Type-species *Etheostoma squamatus* Gilbert and Swain, 1887, by original designation.

Ulocentra Jordan, 1878, Manual of Vertebrates, 2nd ed., p. 223. Type-species *Arlina atripinnis* Jordan, 1877, by monotypy.

Vaillantia Jordan *in* Jordan and Brayton, 1878, U.S. Nat. Mus. Bull. 12, p. 89. Type-species *Boleosoma camurum* Forbes, 1878 (=*Vaillantia chlorosomum* Hay, 1880), by original designation.

Vigil Jordan, 1919, Proc. Acad. Nat. Sci. Philadelphia, vol. 70, p. 344. Substitute name for *Pleurolepis* Agassiz, 1863, preoccupied by *Pleurolepis* Quenstedt, 1852, Pisces. Takes the same type-species as *Pleurolepis* Agassiz, *Pleurolepis pellucidus* Agassiz *in* Putnam, 1863.

Villora Hubbs and Cannon, 1935, Misc. Publ. Univ. Michigan Mus. Zool., no. 30, p. 11. Type-species *Villora edwini* Hubbs and Cannon, 1935, by original designation.

Unavailable Genus-Group Names

Nivicola Jordan and Evermann, 1896, U.S. Nat. Mus. Bull. 47, p. 1082. Type-species *Poecilichthys borealis* Jordan 1884, (=*Boleichthys exilis* Girard, 1859), by original designation; preoccupied by *Nivicola* Hodgson, 1844, Aves.

Pleurolepis Agassiz *in* Putnam, 1863, Bull. Mus. Comp. Zool., vol. 1, p. 5. Type-species *Pleurolepis pellucidus* Agassiz *in* Putnam, 1863, by monotypy; preoccupied by *Pleurolepis* Quenstedt, 1852, Semionotidae.

Poecilisoma Agassiz, 1850, Lake Superior, p. 299. Type-species *Etheostoma variata* Kirtland, 1838, by subsequent designation of Agassiz, 1854, p. 306. Name preoccupied by *Poecilosoma* Huebner, 1819, Lepidoptera; *Poecilosoma* Stephens, 1829, Hemiptera; and *Poecilosoma* Newman, 1838, Coleoptera.

Richia Coker, 1926, Bull. Bur. Fish., vol. 42, p. 106. Type-species *Richia brevispina* Coker, 1926 (=*Etheostoma flabellaris* Rafinesque, 1819), by original designation; preoccupied by *Richia* Grote, 1887, Lepidoptera.

Torrentaria Jordan and Evermann, 1896, U.S. Nat. Mus. Bull. 47, p. 1080. Type-species *Etheostoma australe* Jordan, 1884, by original designation; preoccupied by *Torrentaria* (Hodgson MS) Gray, 1863, Aves.

Nominal Species

Alvarius fonticola Jordan and Gilbert, 1886, Proc. U.S. Nat. Mus., vol. 9, p. 23. Redescribed in more detail as "*Etheostoma* (*Alvarius*) *fonticola* Jordan and Gilbert, sp. nov." in Gilbert (1887, p. 63).

Lectotype: USNM 36523 (♂, 27), Texas, San Marcos R. at San Marcos; D. S. Jordan and C. H. Gilbert; September 1884; figured in Jordan and Evermann (1900, fig. 470); herein selected. D VII–10; A I, 6; LL 2+30=32; INF 3+1; POM 8; supratemporal canal interrupted; nape, cheeks, and breast naked; breeding tubercles on posterior anal rays.

Paralectotypes: USNM 198004 (3, 21–24), removed from USNM 36523.

=*Etheostoma* (*Microperca*) *fonticola* (Jordan and Gilbert).

Alvordius aspro Cope and Jordan *in* Jordan, 1877, Proc. Acad. Nat. Sci. Philadelphia, vol. 29, p. 51, based on the figure but not the description of "*Etheostoma blennioides*" in Kirtland, 1841, Boston Journ. Nat. Hist., p. 3, pl. 6, fig. 1.

Types: This name was proposed as "*Alvordius aspro*, Cope and Jordan, nom. sp. nov.," a replacement name for *Etheostoma blennioides* of Kirtland's figure. However, the name clearly applies to a new species based on Kirtland's misidentified figure. Cope and Jordan did not provide any description, did not mention any localities, and gave no indication of having any material before them. Therefore, the type of *A. aspro* must be the specimen from the Mahoning River, Ohio, from which Kirtland drew his figure. We have not been able to locate this specimen. However, there are two specimens collected by Jordan from the White River in Indiana. One, labeled "paratype," is USNM 20137, and the other, labeled "cotype," is BMNH 1880.1.21.84. In the same year that *A. aspro* was described, Jordan (1877, p. 375) listed *A. aspro* as "frequent" in collections made by Copeland and Jordan in the White River around Indianapolis. The USNM and BMNH specimens should not be considered as type material because the original description was based only on the references to Kirtland's figure.

=*Percina* (*Alvordius*) *maculata* (Girard).

Alvordius crassus Jordan and Brayton, 1878, U.S. Nat. Mus. Bull. 12(A), p. 12.

Lectotype: USNM 23459 (♂, 63), South Carolina, Saluda R., near Greenville; D. S. Jordan and A. B. Brayton; summer, 1877; labeled "drawn"; herein selected by Dr. Edward C. Raney. D XII–13; A II,10; LL 54, complete; cheeks and anterior portion of nape naked;

breast with one enlarged scale; another enlarged scale between pelvic fin bases; opercle covered with scales.

Paralectotypes: USNM 31111 (3, 46–50), same data as lectotype.

=*Percina* (*Ericosma*) *crassa crassa* (Jordan and Brayton).

Alvordius evides Jordan and Copeland *in* Jordan, 1877, Proc. Acad. Nat. Sci. Philadelphia, vol. 29, p. 51.

Lectotype: USNM 17872 (♂, 45), Indiana, Marion Co., White R., near Indianapolis; D. S. Jordan; 1874; herein selected. D XII–13; A II,9; LL 64; INF 8; POM 10; cheeks with a small patch of scales under junction of lateral and infraorbital canals; opercles scaly; nape with scattered scales; breast naked except for one modified scale at center; subocular bar present.

Paralectotypes?: MCZ 24399 (2 ♂, 42–46), same locality as lectotype. We are not certain that MCZ 24399 contains the other two syntypes on which the original description was based.

The original description was based on three specimens. Jordan and Copeland (in Jordan, 1877, p. 8) utilized additional specimens when they described *Ericosma* to contain the previously described *A. evides.* These additional specimens were incorrectly labeled as types: USNM 20119, MCZ 35957, and BMNH 1880.1.21.12–14.

=*Percina* (*Ericosma*) *evides* (Jordan and Copeland).

Alvordius maculatus Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 68.

Syntypes: USNM 1346 (2, ?), Fort Gratiot on Lake Huron; Maj. B. Alvord; listed as thrown away in USNM catalog and we have been unable to find them.

=*Percina* (*Alvordius*) *maculata* (Girard).

Ammocrypta beanii Jordan, 1877, U.S. Nat. Mus. Bull. 10, p. 5.

Holotype: USNM 17833 (♂, 52), Louisiana, Notalbany R., near Tickfaw; T. H. Bean; December 1876.

=*Ammocrypta* (*Ammocrypta*) *beanii* Jordan.

Ammocrypta clara Jordan and Meek, 1885, Proc. U.S. Nat. Mus., vol. 8, p. 8.

Lectotype: USNM 35828 (1, 42), Iowa, Des Moines R. at Ottumwa; D. S. Jordan and S. E. Meek; August 1884. Jordan and Evermann (1896, p. 1063) listed USNM 35828, then containing four specimens, as "type." Linder (1959) selected one specimen as lectotype and removed the other three.

Paralectotypes: USNM 164166 (3, 33–51), out of USNM 35828. Linder overlooked paralectotypes SU 1500 (1, 46) and UMMZ 187510 (2, disintegrated), orig. IU 753, then IU 7323, that are also from the original type series.

The original description was based on the Ottumwa specimens and is followed by "specimens were *also* obtained in Red River at Fulton, Arkansas, and in the Sabine River at Longview, Texas" (italics ours). The Sabine River specimens (USNM 36488) and the Red River specimens (USNM 36337) were labeled paratypes in the USNM collection, but we do not feel they should be considered as such because they are listed in the fashion of "other material."

=*Ammocrypta* (*Ammocrypta*) *clara* Jordan and Meek. See Linder (1959).

Ammocrypta gelida Hay, 1881, Proc. U.S. Nat. Mus., vol. 3, p. 490.

Syntypes: USNM 27425 (2, 44–45), Mississippi, Clarke Co., Chickasawha R. at Enterprise; O. P. Hay; March–April 1880.

=*Ammocrypta* (*Ammocrypta*) *beanii* Jordan.

Ammocrypta vivax Hay, 1883, Bull. U.S. Fish Comm., vol. 2, p. 58.

Holotype: USNM 32213 (1, 39), Mississippi, Pearl R. at Jackson; O. P. Hay; summer, 1881.

=*Ammocrypta* (*Ammocrypta*) *vivax* Hay.

Aplesion potsii Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 102; *potsii* a misprint for *pottsii*.

Holotype: MCZ 1179 (1, 50), Mexico, Chihuahua R. and tribs.; J. Potts; orig. USNM 1179.

=*Etheostoma* (*Oligocephalus*) *pottsii* (Girard).

Arlina atripinnis Jordan, 1877, U.S. Nat. Mus. Bull. 10, p. 10.

Holotype: USNM 20483 (♂, 56), Tennessee, trib. of Cumberland R., near Nashville; A. Winchell; in poor condition; frenum present, dorsal fin pattern clearly that of *Ulocentra*.

=*Etheostoma* (*Ulocentra*) *atripinne* (Jordan).

Arlina effulgens Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 65.

Holotype: USNM 1253 (♂, 56), Washington, D.C., Rock Cr., trib. of Potomac R.; S. F. Baird; 1851.

=*Etheostoma* (*Boleosoma*) *olmstedi olmstedi* Storer. See Cole (1958).

Belophlox mariae Fowler, 1947, Notulae Naturae, no. 191, fig. 1.

Holotype: ANSP 71731 (♂, 55), North Carolina, Moore Co., trib. of outlet of Watson's Lake, about 3 mi. W. of Southern Pines, Little Pee Dee drainage; H. W. Fowler; Oct. 12, 1946.

=*Etheostoma* (*Oligocephalus*) *mariae* (Fowler).

Boleichthys elegans Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 104.

Syntypes: MCZ 24567 (2, 35–40), Texas, Piedrapainte; J. H. Clark under Col. J. D. Graham; U.S. and Mexican Boundary Survey;

orig. USNM 745, then MCZ 84. The USNM catalog gives four for the number of specimens in USNM 745, but we have been unable to find any types other than MCZ 24567.

=*Etheostoma* (*Oligocephalus*) *grahami* (Girard).

Boleichthys eos Jordan *in* Nelson, 1876, Bull. Illinois Mus. Nat. Hist., no. 1, p. 35. Redescribed in more detail as "*Boleichthys eos*, Jordan and Copeland, n. s." *in* Jordan (1877, p. 46).

Syntypes: USNM 23460 (1, 42), Indiana, La Porte Co., Clear Lake; Jordan; summer, 1875. USNM 17848 (9, 27–42), Indiana, Wabash R.; Jordan. USNM 20117 (1, 34), Indiana, Wabash R.; Jordan; in very poor condition.

=*Etheostoma* (*Oligocephalus*) *exile* (Girard). See Hubbs (1926, p. 67).

Boleichthys exilis Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 103.

Syntypes: USNM 1336 (24, 23–33), North Dakota, Little Muddy R., trib. of upper Missouri R.; G. C. Suckley. MCZ 24728 (6, 27–33), same data, all but the largest in poor condition; orig. USNM 1336, then MCZ 114. UMMZ 86492 (1, 31) out of MCZ 24728.

=*Etheostoma* (*Oligocephalus*) *exile* (Girard). See Hubbs (1926. pp. 64–68).

Boleichthys warreni Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 104.

Holotype: MCZ 32952 (1, 42), North Dakota, Cannon Ball R., Hayden under Lt. G. K. Warren, exploration of the upper Missouri and Yellowstone; September 1856. The USNM catalog lists USNM 1327 as the type of *B. warreni*, but we have been unable to find a jar bearing this number. Jordan (1885, p. 869) and Hubbs (1926) wrote that the type was lost. The original description was based on only one specimen, and MCZ 32952 fits it very well.

=*Etheostoma* (*Oligocephalus*) *exile* (Girard). See Jordan (1885) and Hubbs (1926, p. 67).

Boleichthys whipplii Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 103.

Syntypes: MCZ 24569 (1, 39), "Ark.," Coal Cr. [=trib. of Arkansas R. in E. Oklahoma, Hubbs and Black, 1941]; party under Lt. A. W. Whipple, Pacific Railroad Survey, orig. USNM 1333, then MCZ 41. USNM 1333 is listed in USNM catalog as containing two specimens, but we have been able to find only the specimen now cataloged as MCZ 24569.

=*Etheostoma* (*Oligocephalus*) *whipplii whipplii* (Girard). See Hubbs and Black (1941).

Boleosoma aesopus Cope, 1870, Proc. Amer. Philos. Soc., vol. 11, p. 270.

Syntypes: ANSP ?, Pennsylvania, Lycoming Co., Loyalsoc [now Loyalsock] Cr. in the Allegheny region; A. H. Smith. Types of other species described by Cope in this paper were deposited at ANSP, but Fowler (1907) did not mention types of this form, and we have not found them.

=*Etheostoma* (*Boleosoma*) *olmstedi olmstedi* Storer.

Boleosoma Barratti Holbrook, 1855, Journ. Acad. Nat. Sci. Philadelphia, ser. 3, vol. 2, p. 56, pl. 6, fig. 3.

Lectotype: MCZ 24571 (♂, 46), Florida, Holbrook; orig. MCZ 97; herein selected. D X–10; A II, 7; LL 26+24=50; INF 3+1; POM 9; interorbital, breast, and cheeks scaly.

Paralectotypes: MCZ 43090 (4, 37–40) and UMMZ 36598 (♂, 47), removed from MCZ 24571.

=*Etheostoma* (*Hololepis*) *fusiforme barratti* (Holbrook). See Hubbs and Cannon (1935) and Collette (1962).

Boleosoma camurum Forbes *in* Jordan, 1878, Bull. Illinois State Lab. Nat. Hist., vol. 1, no. 2, p. 40.

Syntypes: USNM 27894 (2 ♀, 39), Illinois, Peoria Lake; S. A. Forbes; Oct. 27, 1878. SU 1683 (♀, 44), Illinois. USNM 23455 (♀, 44), Illinois, Illinois R., figured in Jordan and Evermann (1898, fig. 452). MCZ 25053 (♀, 38), Illlinois, Peoria Lake. UMMZ 187505 (1, 39), Illinois, Pekin, orig. IU 506, then IU 4707. There were originally additional syntypes from "Cache R. and Clear Cr., Union Co.; Johnson Co." according to the original description, but we have not been able to locate them. Smith and Bridges (1960) reported that there were no syntypes in the collection of the Illinois Natural History Survey which inherited much of the material of the old Illinois State Laboratory of Natural History.

=*Etheostoma* (*Boleosoma*) *chlorosomum* (Hay) because *camurum* Forbes is preoccupied in *Etheostoma* by *Poecilichthys camurus* Cope.

Boleosoma fusiforme Girard, 1854, Proc. Boston. Soc. Nat. Hist., vol. 5, p. 41.

Lectotype: USNM 1188 (♀, 33), Massachusetts, trib. of Charles R. at Framingham; S. F. Baird; selected by Hubbs and Cannon (1935, p. 78).

Paralectotypes: USNM 94686 (25, 23–36); MCZ 24589 (4, 27–36); orig. USNM 1188, then MCZ 101. UMMZ 86582 (1, 37); out of MCZ 24589.

=*Etheostoma* (*Hololepis*) *fusiforme fusiforme* (Girard). See Hubbs and Cannon (1935) and Collette (1962).

Boleosoma gracile Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, 1859, p. 103.

Lectotype: USNM 1328 (♂, 35), Texas, Río Seco near Ft. Inge; C. B. Kennerly; selected by Hubbs and Cannon (1935, p. 44).

Paralectotypes: MCZ 113 (1, 36), orig. USNM 1328. USNM 1329 (1, 30), Texas, Río Leona near Ft. Inge; Kennerly.

=*Etheostoma* (*Hololepis*) *gracile* (Girard). See Hubbs and Cannon (1935) and Collette (1962).

Boleosoma lepida Baird and Girard, 1853, Proc. Acad. Nat. Sci. Philadelphia, vol. 6, p. 388.

Syntypes: USNM 744 (6, 32–45), Texas, Río Leona at Uvalde, trib. of Nueces R.; J. H. Clark. MCZ 24575 (3, 42–46), same data; orig. USNM 744, then MCZ 82. UMMZ 86335 (1, 41), out of MCZ 24575.

=*Etheostoma* (*Oligocephalus*) *lepidum* (Baird and Girard).

Boleosoma maculaticeps Cope, 1870, Proc. Amer. Philos. Soc., vol. 11, p. 269.

Lectotype: ANSP 13862 (♂, 45), North Carolina, upper waters of Catawba R.; E. D. Cope; selected and illustrated by Fowler (1907, p. 523, fig. 6). All 15 syntypes were still in the same bottle. The next to the largest specimen is closest (55.4 mm.) in total length to the size indicated by Fowler for the "type" (57.0 mm.), and it has the correct number of fin rays: D IX–13; A II,8. These are also the counts given by Cope in the original description. The lectotype has 43 lateral line scales, close to Fowler's figure which has about 45. This specimen herein confirmed as lectotype. INF 8; POM 10; pectoral rays 12–12.

Paralectotypes: ANSP 13863–76 (14, 23–48), same data as lectotype.

=*Etheostoma* (*Boleosoma*) *nigrum maculaticeps* (Cope). See Cole (1958).

Boleosoma maculatum Agassiz, 1850, Lake Superior, p. 305, pl. 4, fig. 3.

Lectotype: USNM 1840 (♂, 43), Ontario, Lake Superior, Ft. William and "the Pic" at the mouth of the Pic R.; L. Agassiz and party; July 13–20, 1848; herein selected by Dr. Charles F. Cole. D IX–13; A I,8; pectoral 12–13; LL 45+3=48; infraorbital pores 4+2; nape, cheeks, and breast naked; opercles partially scaled.

Paralectotype: USNM 197633 (♀, 41), removed from USNM 1840.

=*Etheostoma* (*Boleosoma*) *nigrum nigrum* Rafinesque.

Boleosoma mutatum Vaillant, 1873, Nouv. Arch. Mus. Hist. Nat. Paris, p. 88, a substitute name for *Boleosoma maculatum* Agassiz erroneously thought by Vaillant to be preoccupied in *Boleosoma* by *Etheostoma maculatum* Kirtland.

Types: The types of *B. mutatum* are the same as those of *Boleosoma maculatum* Agassiz.

=*Etheostoma* (*Boleosoma*) *nigrum nigrum* Rafinesque.

Boleosoma nigrum eulepis Hubbs and Greene, 1935, Trans. Wisconsin Acad. Sci., Arts, Lett., vol. 29, p. 96, pl. 3, figs. 1–3.

Holotype: UMMZ 77225 (1, 45), Wisconsin, Dodge Co., trib. of West Branch Rock R., 2 mi. N. of Atwater; C. W. Greene, Stuart, Creaser, and Griffin; Aug. 27, 1927.

Paratypes: UMMZ 100771 (79, 26–47), out of UMMZ 77225. USNM 74927 (2, 33–53), Wisconsin, Turtle Cr. at Delavan; N. Hollister; Oct. 11, 1910. USNM 117505 (3, 45–46), Wisconsin, Marquette Co., Welsh Cr.; Greene and H. S. Jones; Sept. 1, 1925; orig. UMMZ 73880. UMMZ 101528 (9, 25–52), Iowa, Dickinson Co., Spirit L.; J. C. Salyer; July 27, 1932. UMMZ 94832 (22, 26–48), Minnesota, Mississippi R. between Cass L. and Bemidji; Hubbs and Schultz; June 5, 1926. UMMZ 66681 (9, 24–28), Minnesota, Hubbard Co., L. Laselle and outlet; P. A. Moody; Aug. 11, 1925. UW 64 (17, 24–40), Wisconsin, Columbia Co.; Sand (Rock) Cr.; Greene and Jones; Aug. 18, 1925. UW 466 (5, 19–37), Wisconsin, Rock Co., Yahara R. at Indian Ford; G. Wagner; June 23, 1906. UW 467 (2, 40–41), Wisconsin, Walworth Co.; Geneva L.; Wagner; June 26, 1906. UW 473 (22, 24–59), Wisconsin; Manitowoc Co., Mud Cr. at Reedville; Wagner; July 17, 1906. UW 474 (18, 25–31), Wisconsin, Calumet Co., cr. at Brillion; Wagner; July 18, 1906. UW 479 (2, 38–43), Wisconsin, Vilas Co., Trout Lake Cr.; Wagner; July 10, 1907. UW 480 (3, 44–48), Wisconsin, Oneida Co., cr. between Squirrel L. and Diamond L.; Wagner; July 20, 1907.

The following paratypes are all UMMZ specimens from Wisconsin: 72370 (13, 29–54), Polk Co., Apple R., 2 mi. W. of Turtle L. on rt. 14; P. Okkelberg; Aug. 26, 1928. 72382 (13, 23–48), same data. 72414 (60, 25–57), Vilas Co., SE. side of Big Arbor Vitae L.; Metzelaar and Langlois; Sept. 19, 1925. 72447 (9, 36–50), Oneida Co., Kamaguesaga L., W. of Minoigua; Metzelaar and Langlois; Sept. 20, 1925. 72467 (2, 32–37), Vilas Co., Trout L.; Metzelaar and Langlois; Sept. 20, 1925. 72495 (14, 39–53), Vilas Co., Little Arbor Vitae L.; Metzelaar and Langlois; Sept. 21, 1925. 72502 (18, 32–52), Vilas Co., St. Germain L.; Metzelaar and Langlois; Sept. 21, 1925. 73442 (15, 30–49), Columbia Co., Fox R., 10 mi. E. of Portage on rt. 33; Greene and Jones; Aug. 18, 1925. 73458 (1, 42), Columbia Co., French Cr., below dam; Greene and Jones; Aug. 19, 1925. 73464 (35, 32–56), Columbia Co., French Cr., 1 mi. above mill pond; Greene and Jones; Aug. 19, 1925. 73472 (4, 46–56), Columbia Co., Spring Branch Cr., above co. rd.; Greene and Jones; Aug. 19, 1925. 73475 (3, 48–53), same data. 73563 (11, 31–51), Marquette Co., trib. of

Neenah Cr., 1.5 mi. from Neenah Cr.; Greene and Jones; Aug. 21, 1925. 73571 (5, 37–47), Columbia Co., outlet of Spring L., Pardeeville; Greene and Jones; Aug. 22, 1925. 73579 (28, 23–48), Columbia Co., old channel, below Park L. Dam; Greene and Jones; Aug. 22, 1925. 73586 (11, 34–45), Columbia Co., Park L.; Greene and Jones; Aug. 22, 1925. 73627 (89, 27–55), Marquette Co., Neenah Cr., 2 mi. NE. of Briggsville on rt. 23; Greene and Jones; Aug. 24, 1925. 73640 (2, 40–41), Columbia Co., trib. of Neenah Cr., 6 mi. E. of Briggsville; Greene and Jones; Aug. 24, 1925. 73670 (66, 30–48), Marquette Co., Belle Fountaine Cr., 4 mi. N. of Dalton; Greene and Jones; Aug. 25, 1925. 73683 (11, 31–49), Columbia Co., Neenah Cr., near mouth; Greene and Jones; Aug. 26, 1925. 73693 (33, 30–44), Columbia Co., French Cr. at mouth; Greene and Jones; Aug. 26, 1925. 73706 (7, 32–41), Columbia Co., Fox R., below mouth of French Cr.; Greene and Jones; Aug. 26, 1925. 73728 (4, 33–47), Columbia Co., Fox R., opposite Lock 25; Greene and Jones; Aug. 26, 1925. 73735 (6, 41–55), Columbia Co., Fox R. at Portage; Greene and Jones; Aug. 26, 1925. 73744 (47, 28–45), Fond du Lac Co., Grand R., above Fairwater Millpond; Greene and Jones; Aug. 5, 1925. 73810 (14, 34–49), Green Lake Co., Grand R., below Kingston Dam; Greene and Jones; Aug. 29, 1925. 73821 (4, 40–47), Greene Lake Co., Grand R. at Kingston; Greene and Jones; Aug. 29, 1925. 73831 (5, 27–44), Green Lake Co., trib. of Grand R., 4 mi. SW. of Uthey; Greene and Jones; Aug. 31, 1925. 73835 (85, 31–51), Fond du Lac Co., trib. of Grand R., 2 mi. S. of Fairwater; Greene and Jones; Aug. 31, 1925. 73862 (30, 39–51), Green Lake Co., Grand R., 3 mi. S. of Marquette; Greene and Jones; Sept. 1, 1925. 73874 (26, 27–48), Marquette Co., trib. of Grand R., 2 mi. W. of Kingston; Greene and Jones; Sept. 1, 1925. 73877 (8, 38–51), Marquette Co., trib. of Grand R., 1.5 mi. S. of Welsh Cr.; Greene and Jones; Sept. 1, 1925. 73888 (57, 28–55), Marquette Co., trib. of Grand R., Welsh Cr.; Greene and Jones; Sept. 1, 1925. 73955 (34, 26–54), Fond du Lac Co., Rush Cr., near Waupun; Greene and Cuchio; July 4, 1926. 77054 (33, 25–53), Columbia Co., Crawfish R., 2 mi. NW. of Fall R.; Greene and Stuart; Aug. 21, 1927. 77073 (35, 30–48), Dodge Co., Beaver Dam Cr., 5 mi. S. of Beaver Dam; Greene and Stuart; Aug. 21, 1927. 77082 (18, 32–53), Columbia Co., trib. of Crawfish R., 4 mi. NW. of Columbus; Greene and Stuart; Aug. 21, 1927. 77088 (15, 28–44), Columbia Co., trib. of Crawfish R. just N. of Columbus on rt. 16; Greene and Stuart; Aug. 22, 1927. 77096 (3, 33–40), Columbia Co., Crawfish R. at Columbus; Greene and Stuart; Aug. 22, 1927. 77110 (5, 32–39), Dodge Co., trib. of Crawfish R., 10 mi. W. of Watertown on rt. 19; Greene and Stuart; Aug. 23, 1927. 77125 (8, 31–46), Dodge Co., trib. of Beaver Dam Cr., 2 mi. E. of Lowell on rt. 16; Greene and

Stuart; Aug. 23, 1927. 77135 (6, 28–39), Dodge Co., W. Branch of Rock R., above millpond at Hustisford; Greene and Stuart; Aug. 27, 1927. 77153 (2, 37–41), Dodge Co., Beaver Dam Cr., below dam at Fox L.; Greene and Stuart; Aug. 26, 1927. 77165 (11, 32–45), Dodge Co., Crawfish R., 8 mi. N. of Watertown; Greene and Stuart; Aug. 26, 1927. 77208 (22, 27–44), Dodge Co., Old Mill Cr., 1 mi. S. of Atwater; Greene, Stuart, Creaser, Griffin; Aug. 27, 1927. 77232 (44, 25–49), Fond du Lac Co., W. Fk. of Upper W. Br. of Rock R., 4 mi. NW. of Waupun; Greene, Stuart, Creaser, Griffin; Aug. 29, 1927. 77592 (32, 21–44), Jefferson Co., Rock R., below Ft. Atkinson; Schultz and Tarzwell; Aug. 7, 1928. 77779 (30, 26–56), St. Croix Co., Apple R., above Somerset; Schultz and Tarzwell; Aug. 11, 1928. 78384 (6, 24–40), Rock Co., Rock R., 2.5 mi. N. of Beloit; Schultz and Tarzwell; Aug. 27, 1928. 78415 (43, 24–37), same data. 95933 (3, 26–49), Sawyer Co., Grindstone L., 10 mi. SE. of Haywood; Creaser and Jones; Sept. 2, 1928. 96111 (9, 24–48), Washburn Co., Trough L., 14 mi. SE. of Spooner on rt. 53; Creaser and Jones; Sept. 7, 1928. 96234 (15, 30–61), Polk Co., Apple R. at Amery; Creaser and Jones; Sept. 11, 1928. 96254 (13, 28–40), Polk Co., Balsam L. at Balsam City; Creaser and Jones; Sept. 12, 1928. 96570 (11, 43–52), Vilas Co., Trout L.; Wright; Aug. 6, 1927. 96573 (7, 20–48), Vilas Co., Trout L.; Wright; Aug. 4, 1927. 96703 (4, 43–47), Vilas Co,. Trout L.; Wright; Aug. 4, 1927. 100202 (2, 37–45), Vilas Co., Silver L.; Schneeberger; July 19, 1932.

=? *Etheostoma* (*Boleosoma*) *nigrum nigrum* Rafinesque. See Lagler and Bailey (1947) and Underhill (1963). We agree with Underhill that recognition of the scaly populations of *E. nigrum* as a subspecies does not aid in understanding the complex distributional pattern of the two morphological types present in the Great Lakes and upper Mississippi regions.

Boleosoma olmstedi var. *brevipinnis* Cope, 1868, Journ. Acad. Sci. Philadelphia, ser. 2, vol. 6, p. 214.

Lectotype: ANSP 22653 (♂, 46), Pennsylvania, Kiskiminitas R., trib. of Allegheny R.; E. D. Cope; number selected by Fowler (1907, p. 522 misprinted as "25,563 (type) to 22,567"), but all syntypes found still mixed together. Largest specimen herein selected as lectotype. D VIII–11; A I,9; LL 38+4=42; INF 4+3; pectoral rays 12–12; nape, preopercle, and breast naked; anterior part of belly naked.

Paralectotypes: ANSP 22654–67 (14, 34–40), same data as lectotype.

Cope mentioned two additional specimens of this form from the Holston River. Fowler did not list these as types. We feel it is best not to consider these specimens as paralectotypes and formally restrict the type locality to the Kiskiminitas River.

=*Etheostoma* (*Boleosoma*) *nigrum nigrum* Rafinesque.

Boleosoma perlongum Hubbs and Raney, 1946, Misc. Publ. Mus. Zool. Univ. Michigan, no. 65, p. 17, pl. 1, fig. 3.

Holotype: UMMZ 138475 (♂, 71), North Carolina, Columbus Co., N. shore of Lake Waccamaw; E. C. Raney, E. A. Lachner, and R. A. Pfeiffer; Mar. 30, 1941; orig. CU 9285.

Paratypes: UMMZ 138476 (16, 44–75), same data as holotype.

=*Etheostoma* (*Boleosoma*) *perlongum* (Hubbs and Raney). See Cole (1958).

Boleosoma phlox Cope, 1880, U.S. Nat. Mus. Bull. 17, p. 30.

Holotype: ANSP 20447 (1, 34), Texas, Trinity R. at Fort Worth; E. D. Cope. We have found no other type material and cannot determine if the original description was based on one or more specimens. The label says "type." Fowler (1907) referred to ANSP 20447 as "type," not cotype, so we assume this specimen is the holotype.

=*Etheostoma* (*Oligocephalus*) *lepidum* (Baird and Girard).

Boleosoma stigmaeum Jordan, 1877, Ann. New York Lyceum Nat. Hist., vol. 11, p. 311.

Lectotype: ANSP 20645 (♂, 39), Georgia, Floyd Co., Etowah R., trib. of Coosa R. near Rome; D. S. Jordan and C. H. Gilbert; summer, 1876; selected by Bailey, Winn, and Smith (1954, p. 142).

Paralectotypes: ANSP 20646–48 (3, 36–39), same data as lectotype. One syntype was figured by Fowler (1907, fig. 5).

Although labeled as a syntype of *B. stigmaeum*, USNM 31108 is a specimen of *Etheostoma* (*Ulocentra*) *coosae* (Fowler).

=*Etheostoma* (*Boleosoma*) *stigmaeum* (Jordan).

Boleosoma susanae Jordan and Swain, 1883, Proc. U.S. Nat. Mus., vol. 6, p. 249.

Lectotype: USNM 36501 (♂, 41), Kentucky, Whitley Co., trib. of Clear Fk., Cumberland R. near Pleasant View; D. S. Jordan and J. Swain; May 1883; herein selected by Dr. Charles F. Cole. D VIII–12; A I,9; pectoral 11–11; LL 40+4=44; infraorbital canal 4+2; preoperculomandibular pores 9; cheeks, opercles, nape, breast, and anterior half of belly naked.

Paralectotypes: USNM 197634 (7, 25–30), removed from USNM 36501.

=*Etheostoma* (*Boleosoma*) *nigrum susanae* (Jordan and Swain), apparently a valid subspecies.

Boleosoma tessellatum DeKay, 1842, Nat. Hist. New York Zool., vol. 1, pt. 4, p. 20, pl. 20, fig. 57.

Syntypes: Description and figure based on specimens then in New York State collection. Dr. E. M. Reilly, Curator of Zoology, has informed us that the types of this species are no longer present in the New York State Museum.

=*Etheostoma* (*Boleosoma*) *olmstedi olmstedi* Storer. See Cole (1958). Described after July 1, 1842, because that is the date on the preface to part 4, "Fishes," of the "Zoology of New York." Thus *Etheostoma olmstedi* Storer, January 1842 has priority.

Boleosoma vexillare Jordan, 1880, Proc. U.S. Nat. Mus., vol. 2, p. 235.

Holotype: ? (♂, 2½ in. TL), Virginia, Rappahannock R. at Warrenton. Jordan and Evermann (1896, p. 1058) wrote that the type was in the Charles Hallock collection. Cole was unable to find the type during the course of his thesis work on the subgenus *Boleosoma*, and we have also been unable to find it.

=*Etheostoma* (*Boleosoma*) *olmstedi vexillare* (Jordan). See Cole (1958).

Catonotus fasciatus Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 68.

Lectotype: USNM 1345 (♂, 60), New York, Grass R., near Madrid; E. O. Dayton; 1852; herein selected. D VIII–14; A II,7; LL 32+21=53; INF 4+2; POM 9; supratemporal canal moderately interrupted; about 10 dark vertical bars on side of body.

Paralectotypes: USNM 197997 (♂, 53), removed from USNM 1345. USNM 1393 (4, 27–41), New York, Madrid; Dayton; 1852. MCZ 24652+24656 (6, 21–58), same locality; 1853. MCZ 24652 ("2") was originally USNM 1187, then MCZ 22. MCZ 24656 ("6") was originally USNM 1393, then MCZ 21.

=*Etheostoma* (*Catonotus*) *flabellare flabellare* Rafinesque.

Catonotus Kennicotti Putnam, 1863, Bull. Mus. Comp. Zool., vol. 1, p. 3.

Lectotype: USNM 1365 (♂, 35), Illinois; Union Co., a rocky brook; R. Kennicott; April 1857; herein selected. D VII–14; A II,7; LL 25+28=53; INF 4+2; POM 10; supratemporal canal moderately interrupted; cheeks, opercles, and breast naked; nape with few, scattered, imbedded scales; branchiostegal membranes moderately connected; tips of dorsal spines with bony knobs; about 10 horizontal lines on body.

Paralectotypes: USNM 198002 (20, 29–41), removed from USNM 1365. USNM 154713 (7, 27–42), same data; orig. USNM 1365, then Wesleyan Univ. 554; specimens badly dried out. MCZ 24658 (6, 29–50), same data; orig. USNM 1365, then MCZ 2. UMMZ 86347 (1, 42), out of MCZ 24658. MCZ 24665 (♂, 52; 3♀, 31–47), same locality; April–May 1856; orig. USNM 1811, then MCZ 37.

USNM 154784 (1, 42), same data; orig. USNM 1811, then Wesleyan Univ. 558.

=*Etheostoma* (*Catonotus*) *kennicotti* (Putnam).

Catonotus lineolatus Agassiz, 1854, Amer. Journ. Sci. and Arts, vol. 17, p. 305.

Lectotype: MCZ 24637+24657 (♂, 46), Illinois, small creeks near Quincy; L. Watson; 1853; orig. USNM 1801, then MCZ 1; herein selected. D VII–14; A II,8; LL 24+29=53; INF 4+2; POM 10; supratemporal canal incomplete; interorbital pores present; head and breast naked; humeral spot prominent; tips of dorsal spines widened; about seven rows of fine longitudinal stripes on the body above the lateral line; branchiostegal membranes broadly connected.

Paralectotypes: MCZ 43093 (5, 30–39) and UMMZ 86481 (2♂, 41–52) removed from MCZ 24637+24657. MNHN 2785 (♂, 43), same locality, orig. MCZ 859.

=*Etheostoma* (*Catonotus*) *flabellare lineolatum* (Agassiz).

Cottogaster aurantiacus Cope, 1868, Journ. Acad. Nat. Sci. Philadelphia, ser. 2, vol. 6, p. 211, color pl. 24, fig. 6.

Lectotype: ANSP 13789 (1, 55), Virginia, N. Fork of Holston R.; E. D. Cope; 1867; number selected by Fowler (1907, p. 521); specimen herein selected. D XV–14; A II,10; LL 91.

Paralectotype: ANSP 13790 (1, 55), same data as lectotype.

=*Percina* (*Hypohomus*) *aurantiaca* (Cope).

Cottogaster cheneyi Evermann and Kendall, 1898, Bull. U.S. Fish Comm., vol. 17, p. 129, pl. 8, fig. 8.

Holotype: USNM 48781 (♂, 51), New York, St. Lawrence Co., Racket R. [now Raquette R.], near Norfolk; B. W. Evermann and B. A. Bean; July 18, 1894; figured in Jordan and Evermann (1900, fig. 445).

Paratypes: USNM 48782 (4, 39–47); USNM 126978 (4, 40–47), orig. BF 527; and SU 9048 (4, 40–49), orig. given as SU 5774; all with same data as holotype.

=*Percina* (*Cottogaster*) *copelandi* (Jordan).

Cottogaster putnami Jordan and Gilbert, 1883, U.S. Nat. Mus. Bull. 16, p. 498.

Lectotype: USNM 1314 (♂, 45), New York, Westport Br., Lake Champlain; S. F. Baird; September 1853; orig. no. 55; herein selected. D XI–12; A II,9; LL 48; INF 8; POM 10; cheeks naked; breast naked except for a large modified scale in the center and another between the bases of the pelvic fins; nape naked anteriorly; opercles scaly. This name was proposed as "nom. sp. nov." for *Boleosoma tessellatum* of Thompson (1853), Putnam (1863), and others, not of

DeKay. *Cottogaster putnami* was actually being proposed as the name of a new species and not as a substitute name, so the collection on which the description was based, USNM 1314, becomes the type material.

Paralectotypes: USNM 198000 (27, 35–49), removed from USNM 1314 + USNM 1193. USNM 1193, with the same locality and collector as USNM 1314, is now mixed with 1314 and may have been so at the time of the original description. All the specimens are the same species. At least one syntype of *C. putnami* out of USNM 1314 was included in a gift to the University of Cincinnati, dated Oct. 30, 1884.

=*Percina* (*Cottogaster*) *copelandi* (Jordan).

Diplesion fasciatus Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 101.

Lectotype: MCZ 24625 (♂, 45), Mexico, Chihuahua R.; J. Potts; orig. USNM 743 (6)+USNM 1192 (3)+USNM 1206 (1), then MCZ 87; herein selected. D X–12; A I,7; LL 46+13=59; INF 9; POM about 10; interorbital, parietal, nape, cheeks, opercle, and breast naked; anal spine very strong.

Paralectotypes: MCZ 43092 (♂, 42; ♀, 42) and UMMZ 86349 (♀, 41), removed from MCZ 24625.

=*Etheostoma* (*Austroperca*) *australe* Jordan because *fasciatus* is preoccupied in *Etheostoma* by *Catonotus fasciatus* Girard.

Estrella atromaculata Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 66.

Types: We have been unable to find type material of this form. During the course of his thesis work on the subgenus *Boleosoma*, Cole was also unable to locate any types. The original description was based on specimens from "the Potomac River, in the neighborhood of Washington."

=*Etheostoma* (*Boleosoma*) *olmstedi atromaculatum* (Girard). See Cole (1958).

Etheostoma (*Nothonotus*) *acuticeps* Bailey, 1959, Occ. Pap. Mus. Zool. Univ. Michigan, no. 603, pl. 1.

Holotype: UMMZ 159014 (♂, 58), Tennessee, Sullivan Co., S. Fork of Holston R., 0.5 mi. above S. Holston Dam, 7 mi. SE. of Bristol; R. M. Bailey, G. P. Cooper, and J. D. Kilby; June 23, 1949.

Paratypes: UMMZ 159013 (3, 49–51), same data as holotype. UMMZ 157585 (2, 45–52), same locality, R. M. Bailey, R. W. Eschmeyer, and J. Chance; Sept. 23, 1947.

=*Etheostoma* (*Nothonotus*) *acuticeps* Bailey.

Etheostoma arcus-celestis Crevecoeur, 1903, Trans. Kansas Acad. Sci., vol. 18, pp. 177–178.

Syntypes: USNM?, Kansas, Pottawatomie Co., French Cr., trib. of Vermillion R. near Onaga; F. F. Crevecoeur; April–May 1902. The types were sent to the U.S. National Museum in 1907 along with specimens of *Campostoma anomalum* and *Semotilus atromaculatus*. We have located the minnows (USNM 72474 and 70457) but have been unable to find the types of *E. arcus-celestis*.

=*Etheostoma* (*Oligocephalus*) *spectabile pulchellum* (Girard) according to Mr. Donald A. Distler (pers. comm.).

Etheostoma aubeenaubei Evermann, 1900, Rept. U.S. Fish Comm., vol. 25, p. 367, pl. 17.

Holotype: USNM 65248 (♀, 41), Indiana, Marshall Co., Aubeenaubee Cr., E. inlet of Lake Maxinkuckee; Evermann and Scovell; Aug. 23, 1899; erroneously given as USNM 49379 in original description.

Paratypes: All from Aubeenaubee Cr., Indiana. USNM 65255 (2, 38–39), Aug. 23, 1899. USNM 65258 (10, 34–40), Aug. 4, 1899. USNM 65260 (69, 35–40), Aug. 23, 1899. Two paratypes out of USNM 65260 were given to the Lebanon City Schools, Lebanon, Wis., Apr. 5, 1911. USNM 65249 (10, 25–30); Long Point; Aug. 11, 1899. USNM 65263 (5, 30–34), Aug. 8, 1899.

=*Etheostoma* (*Oligocephalus*) *exile* (Girard). See Hubbs (1926, p. 68).

Etheostoma (*Etheostoma*) *australe* Jordan, 1889, Proc. U.S. Nat. Mus. vol. 11, p. 362, replacement name for *Diplesion fasciatus* Girard, preoccupied in *Etheostoma* by *Catonotus fasciatus* Girard.

Lectotype: MCZ 24625 (♂, 45). See *Diplesion fasciatus*.

Paralectotypes: MCZ 43092 and UMMZ 86349.

=*Etheostoma* (*Austroperca*) *australe* Jordan.

Etheostoma blennioides Rafinesque, 1819, Journ. Phys., Chim., Hist. Nat., Arts, vol. 88, p. 419.

Types: As Call (1899) has noted, Rafinesque did not preserve any type material. Type locality Ohio River. Examination of a photograph of a sketch of this species from Rafinesque's notebook (fig. 1) confirms the attribution of the name *blennioides* to the species currently known by this name.

=*Etheostoma* (*Etheostoma*) *blennioides blennioides* Rafinesque. See Miller (1964).

Etheostoma (*Rhothoeca*) *blennius* Gilbert and Swain *in* Gilbert, 1887, Proc. U.S. Nat. Mus., vol. 10, p. 55.

Holotype: USNM 36187 (1, 60), Alabama, Cox's Cr., trib. of Tennessee R. near Florence; C. H. Gilbert and J. Swain; summer, 1884.

Paratype: SU 1955 (1, 47), Alabama, Shoal Cr., trib. of Tennessee R. near Florence; Gilbert and Swain; summer, 1884.

=*Etheostoma* (*Etheostoma*) *blennius* Gilbert and Swain. See Hubbs and Black (1940).

Etheostoma caerulea D. H. Storer, 1845, Proc. Boston Soc. Nat. Hist., vol. 2, p. 47. Original description repeated almost verbatim, with the addition of color changes in alcohol, in Storer (1846).

Holotype: MCZ 32949 (♀, 53), Illinois, Fox R.; S. C. Clark.

=*Etheostoma* (*Oligocephalus*) *caeruleum caeruleum* Storer. See Trautman (1930) and Knapp (1964).

Etheostoma cinerea D. H. Storer, 1845, Proc. Boston Soc. Nat. Hist., vol. 2, p. 49. Original description repeated almost verbatim in Storer (1846).

Syntypes: MCZ ?, Alabama, Florence; received from C. A. Hentz. We have been unable to find any types.

=*Etheostoma* (*Allohistium*) *cinereum* Storer. See Bailey and Gosline (1955).

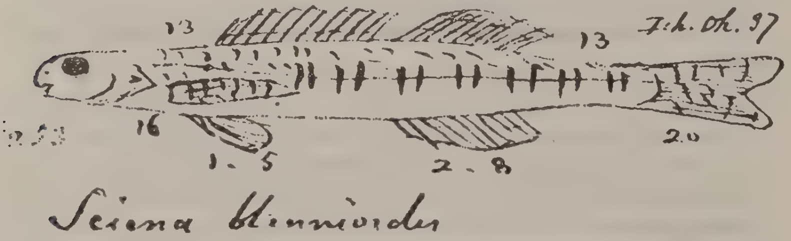

Figure 1.—*Etheostoma blennioides* Rafinesque (sketch from Rafinesque's notebook).

Etheostoma (*Hololepis*) *collis lepidinion* Collette, 1962, Tulane Stud. Zool., vol. 9, no. 4, p. 194, figs. 17, 18.

Holotype: USNM 179847 (♂, 40), Virginia, Charlotte Co., trib. of Horsepen Cr., 2.4 mi. NW. of Wyliesburg on Va. 907; B. B. Collette, C. F. Cole, J. G. New, E. C. Raney, C. R. Robins; Mar. 31, 1956.

Paratypes: CU 29992 (8, 30–38), same data as holotype. USNM 100215 (3, 29–31), Virginia, Charlotte Co., Wards Fork, trib. of Roanoke R., S. of Madisonville; S. Abraham; Apr. 23, 1935. USNM 101330 and 101334 (12, 22–29), Virginia, Charlotte Co., Wards Fork, Roanoke Cr., below mill dam between Madisonville and Cullen; G. S. Myers and Abraham; Sept. 15, 1935. CU 34544 (7, 29–40), Virginia, Charlotte Co., Wards Fork Cr., 6.7 mi. SSW. of Madisonville on Va. 47; Collette and J. S. Ramsey; Sept. 16, 1959. DU uncat. (♂, 38), North Carolina, Granville Co., Beech Cr., 3 mi. NNE. of Cornwall (now flooded by Kerr Dam); J. R. Bailey 52–7; spring, 1952. DU uncat. (5♀, 31–36), North Carolina, Durham Co., Lick Cr. on rt. 264, 4.5 mi. E. of Oak Grove; Bailey and Walter; Apr. 6, 1950. DU uncat. (♂, 36), North Carolina, Orange Co., Eno R., 2 mi. W. of Hillsboro; J. R. Bailey 49–9; Mar. 20, 1949. DU uncat. (♀, 38), North Carolina, Orange Co., Eno R. at ford N. of Hillsboro near Skipper Wright's; J. R. Bailey 55–3; Apr. 21, 1955.

=*Etheostoma* (*Hololepis*) *collis lepidinion* Collette.

Etheostoma cragini Gilbert, 1885, Bull. Washburn College Lab. Nat. Hist., vol. 1, no. 3, p. 99.

Lectotype: USNM 38320 (1, 33), Kansas, Finney Co., small brook leading from the "Lake" at Garden City to Arkansas R.; F. W. Cragin; March–April 1885; USNM 38320 listed by Jordan and Evermann (1896, p. 1092) as "type" then containing three specimens; lectotype herein selected. D IX–12; A II,6; LL 19+32=51; POM 10; INF 7 pores on right, 8 on left; supratemporal canal widely interrupted; cheeks and opercles naked; breast and prepectoral area with few, imbedded scales.

Paralectotypes: USNM 197994 (2, 29), removed from USNM 38320. USNM 125109 (1, 23), same data, orig. BF 309.

Additional syntypes from SU 2141 became mixed with SU 694 from Canon City, Colo. and so were not considered for selection of a lectotype.

=*Etheostoma* (*Oligocephalus*) *cragini* Gilbert.

Etheostoma cumberlandicum Jordan and Swain, 1883, Proc. U.S. Nat. Mus. vol. 6, p. 251.

Lectotype: USNM 36502 (♂, 41), Kentucky, Whitley Co., Wolf Cr., trib. of Clear Fork, Cumberland R., near Pleasant View; D. S. Jordan, J. Swain, C. H. Gilbert; May 1883; herein selected. This specimen was found alone in a bottle with three labels, each reading "type". Four additional specimens were found in another bottle, also labeled USNM 36502, *Etheostoma cumberlandicum*. The single specimen is in as good condition as the largest of the four, so it is selected lectotype. D VII–11; A II,7; LL 25+19=44; INF 4+1; POM 10; supratemporal canal interrupted; preopercle smooth; cheeks, opercles, nape, and breast naked.

Paralectotypes: USNM 197992 (4, 20–42), removed from USNM 36502.

=*Etheostoma* (*Catonotus*) *flabellare cumberlandicum* Jordan and Swain. See Ross and Carico (1963, p. 12).

Etheostoma (*Hadropterus*) *cymatotaenia* Gilbert and Meek *in* Gilbert, 1887, Proc. U.S. Nat. Mus., vol. 10, p. 51.

Lectotype: USNM 36215 (♂, 68, labeled "drawn"), Missouri, Niangua R., near Marshfield; C. H. Gilbert and S. E. Meek; summer, 1884; herein selected; (fig. 2). D XII–12; A II,10; LL 66; branchiostegal membranes slightly connected; opercles, cheeks, breast, and belly scaly; midventral belly scales slightly modified; thin flangelike midventral keel on lower edge of caudal peduncle near caudal base.

Paralectotypes: USNM 198090 (♂, 63), removed from USNM 36215. USNM 36260 (2 ♂, 63–68), Missouri, Osage Fork of Gasconade R., near Marshfield; Gilbert and Meek; summer, 1884; erroneously given as USNM 38260 in original description and in Jordan and Evermann (1896, p. 1042). USNM 36308 (5, 40–44), Missouri, Sac R., near Greenfield; Gilbert and Meek; summer, 1884. SU 2603 (4, 39–54), same data as USNM 36308.

Additional syntypes from SU 3949, with the same data as USNM 36215, became mixed with nontype specimens from Kentucky, collected by A. J. Woolman as a result of the 1906 earthquake.

=*Percina* (*Hypohomus*) *cymatotaenia* (Gilbert and Meek).

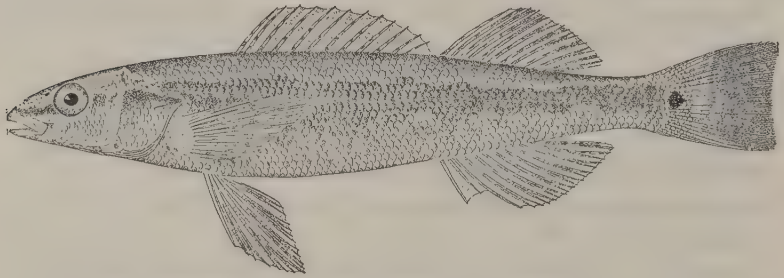

FIGURE 2.—*Etheostoma cymatotaenia* Gilbert and Meek (previously unpublished drawing of lectotype drawn in October 1884).

Etheostoma (*Ulocentra*) *davisoni* Hay, 1885, Proc. U.S. Nat. Mus., vol. 8, p. 554.

Holotype: USNM 37365 (1, 41), Florida, Santa Rosa Co., Yellow R., near Chaffin; H. T. Mann and D. M. Davison; April 1885.

=*Etheostoma* (*Boleosoma*) *davisoni* Hay. *Etheostoma davisoni* has long been considered a synonym of *E. stigmaeum*. However, *E. davisoni* has recently been recognized as a distinct species by Mr. William Mike Howell, who is presently studying the taxonomy and systematics of this group. His validation of *E. davisoni* will appear elsewhere.

Etheostoma (*Oligocephalus*) *ditrema* Ramsey and Suttkus, 1965, Tulane Stud. Zool., vol. 12, no. 3, p. 66, figs. 1–3.

Holotype: TU 35703 (♂, 34) Georgia, Chattooga Co., trib. to Mills Cr., trib. to Chattooga R., 4.3 airline mi. W. of Lyerly; July 18, 1962.

Paratypes: TU 29153 (21, 15–35), out of TU 35703. The following are all from the type locality. TU 26086 (8, 24–31), Apr. 19, 1962; TU 27566 (9, 18–34), May 30, 1962; TU 32762 (34, 19–42), June 1, 1964; TU 32981 (43, 20–39), June 23, 1964. Five paratypes out of TU 32981 were sent to each of the following institutions: USNM 198607 (29–32), MCZ 43123 (29–37), ANSP 101231 (26–32), CU 47872 (30–32), SU 62401 (27–36), and UMMZ 187501 (29–36). Also ANSP 20649 (1, 23), Georgia, Floyd Co., near Rome; summer, 1876; D. S. Jordan.

=*Etheostoma* (*Oligocephalus*) *ditrema* Ramsey and Suttkus.

Etheostoma duryi Henshall, 1889, Journ. Cincinnati Soc. Nat. Hist., vol. 11, p. 32.

Syntypes: Cincinnati Soc. Nat. Hist. (3 ♂, 2 ♀, 2–3 in.), Tennessee, small trib. of Tennessee R. at Whiteside on Memphis and Charleston RR.; C. Dury. We have been unable to locate any of the syntypes.

=*Etheostoma* (*Ulocentra*) *duryi* Henshall.

Etheostoma flabellaris Rafinesque, 1819, Journ. Phys., Chim., Hist. Nat., Arts, vol. 88, p. 419.

Types: As Call (1899) indicated, Rafinesque did not preserve any of his type material. Type locality—the Ohio R. The sketch of this species in Rafinesque's notebook (fig. 3) leaves no doubt as to the identity of what Rafinesque had before him.

=*Etheostoma* (*Catonotus*) *flabellare flabellare* Rafinesque.

Etheostoma fontinalis Rafinesque, 1820, Ichthyologia Ohiensis, p. 85.

Types: As Call (1899) noted, Rafinesque did not preserve types. Type locality—"in the springs and caves near Lexington."

=*Etheostoma* (*Catonotus*) *flabellare flabellare* Rafinesque according to Jordan and Evermann (1896, p. 1097).

Etheostoma formosa Henshall, 1889, Journ. Cincinnati Soc. Nat. Hist., vol. 11, p. 32.

Holotype: Cincinnati Soc. Nat. Hist. (1, 2½ in.), Tennessee, small trib. of Tennessee R. at Whiteside on Memphis and Charleston RR.; C. Dury. We have been unable to locate the type.

=*Etheostoma* (*Oligocephalus*) *caeruleum* ssp. See Knapp (1964).

Etheostoma fricksia Hildebrand, 1923, Bull. Bur. Fish., vol. 39, p. 7, fig. 1.

Holotype: USNM 82633 (♂, 44), Georgia, Richmond Co., Savannah Dr., small creek on Sanitary Dairy Farm near Augusta; S. F. Hildebrand; Mar. 26, 1918.

Paratypes: USNM 92818 (♂, 31; 2♀, 33–47), same data as holotype.

=*Etheostoma* (*Oligocephalus*) *fricksium* Hildebrand. See Bailey and Richards (1963).

Etheostoma güntheri Eigenmann and Eigenmann, 1892, Amer. Nat., vol. 26, p. 962. Description much enlarged in Eigenmann (1894).

Lectotype: BMNH 1892.12.30.151 (♂, 41), Canada, Manitoba, Red R. of the North at Winnipeg; C. H. Eigenmann; August–September 1892; herein selected. D IX–13; A II,10; LL 57; moderate frenum present; posterior rays of anal fin extending beyond posterior end of depressed second dorsal; black spot at anterior and posterior ends of first dorsal.

Paralectotypes: BMNH 1892.12.30.152–153 (2, 41–51), same data as lectotype.

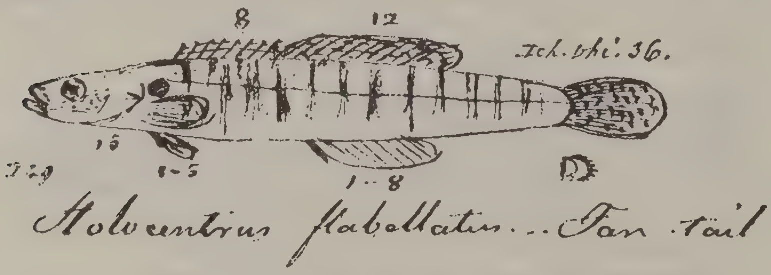

Figure 3.—*Etheostoma flabellare* Rafinesque (sketch from Rafinesque's notebook).

Three other specimens are mentioned, both in the original description and in the 1894 paper. We do not think that these should be considered as syntypes. USNM 45567 (♂, 42) and UMMZ 187522 (2, 31–42), orig. IU 1449, then IU 4506, Iowa, Cedar Rapids; S. E. Meek.

=*Percina* (*Imostoma*) *shumardi* (Girard). See Hubbs and Greene (1928, p. 384).

Etheostoma hildebrandti Evermann and Clark, 1910, Proc. Biol. Soc. Washington, vol. 23, p. 87, fig. 1.

Holotype: USNM 64616 (1, 43), Indiana, Fulton Co., Fletcher Lake, 12 mi. N. of Logansport near Cass Co. line; B. W. Evermann and H. W. Clark; Oct. 6, 1900.

=*Etheostoma* (*Oligocephalus*) *exile* (Girard).

Etheostoma (*Ulocentra*) *histrio* Jordan and Gilbert *in* Gilbert, 1887, Proc. U.S. Nat. Mus., vol. 10, p. 47.

Lectotype: USNM 36386 (♂, 42), Oklahoma, Poteau R., W. of Hackett City, Ark.; D. S. Jordan and C. H. Gilbert; summer, 1864; herein selected by Dr. Chu-fa Tsai. D IX–13; A II,7; LL 53; INF 4+3; POM 9; belly and breast naked; cheek with 6 imbedded scales; opercle with 2 scales; 6 dorsal blotches.

Paralectotypes: USNM 188972 (3, 24–33), removed from USNM 36386. SU 2682 (2, 33–35), same data. USNM 36409 (4, 24–35) and SU 569 (1, 32), Arkansas, Clark Co., Washita (Ouachita) R. at Arkadelphia; Jordan and Gilbert; summer, 1884. USNM 36448 (3, 30–34), Arkansas, Saline Co., Saline R. at Benton, just above railroad bridge; Jordan and Gilbert; summer, 1884.

=*Etheostoma* (*Etheostoma*) *histrio* Jordan and Gilbert.

Etheostoma (*Oligocephalus*) *hopkinsi binotatum* Bailey and Richards, 1963, Occ. Pap. Mus. Zool. Univ. Michigan, no. 630, pl. 1, B–C.

Holotype: CU 44157 (♂, 53), South Carolina, Abbeville Co., Calhoun Cr., 7.6 mi. E. of Calhoun Falls on S.C. 72; E. C. Raney, C. R. Robins, R. H. Backus, R. W. Crawford, J. N. Layne, and R. L. Wigley; ECR 1932; Mar. 27, 1951; orig. CU 19600.

Paratypes: CU 19600 (14, 37–55) and UMMZ 180075 (♂, 48; 3 ♀, 44–50), same data as holotype. Apparently the "additional specimens examined" by Bailey and Richards must also be considered as paratypes because they form part of the type-series as defined by Article 72b of the International Code of Zoological Nomenclature and were not referred to as variants, doubtfully associated with the nominal form, or expressly excluded from it. CU 48401 (1, 38), Georgia, Madison Co., S. Fork of Broad R., 2 mi. W. of Comer; Nov. 1, 1952, Ichthyology Class; orig. UG 269. CU 48399 (1, 33), Georgia, Madison Co., S. Fork of Broad R., 1–2 mi. S. of Carlton; Apr. 11, 1954; orig. UG 22E. CU 48400 (1, 46), Georgia, Madison Co., S. Fork of Broad R., 1–2 mi. S. of Carlton; Apr. 19, 1954; Ichthyology Class; orig. UG 22D. CU 48396 (5, 30–49), Georgia, Oglethorpe-Madison cos., S. Fork of Broad R., Anthony Shoals, near Carlton; Nov. 1, 1952; Ichthyology Class; orig. UG 22C. CU 43994 (♂, 48), Georgia, Madison Co., S. Fork of Broad R., Anthony Shoals, near Carlton; Sept. 3, 1950; W. J. Houck. UMMZ 133122 (3, 32–47), Georgia, Oglethorpe Co., Dry Fork Cr.; O. K. Fletcher; Nov. 3, 1940. UMMZ 133224 (8, 27–42), Georgia, Oglethorpe Co., Dry Fork Cr.; Fletcher; Feb. 8, 23, 1941. UMMZ 137773 (31, 27–43), Georgia, Oglethorpe-Wilkes cos., Dry Fork Cr., about 1 mi. N. of U.S. 78; Fletcher; Mar. 11, Apr. 13, 1941. CU 48398 (2, 38–46), Georgia, Oglethorpe Co., Buffalo Cr., 6 mi. E. of Lexington; Apr. 29, 1953; B. Martof; orig. UG 283. CU 48397 (2, 30–41), Georgia, Columbia Co., W. Fork of Cliatt Cr.; July 24, 1948; orig. UG 90. CU 48402 (15, 21–51), Georgia, Lincoln Co., Lloyds Cr.; July 23, 1948; Scott and Tyson; orig. UG 80. USNM 179063 (4, 37–49), South Carolina, Anderson Co., Twenty-three Mile Cr., 0.9 mi. NW. of Sandy Springs, 11.1 mi. NW. of Anderson on U.S. 76; Mar. 25, 1951; Raney, Robins, Backus, Crawford, Layne, Wigley; orig. CU 19604. CU 43515 (6, 23–39), South Carolina, Edgefield Co., 3 mi. E. of Edgefield Co. line on Ga. 23; Apr. 3, 1953; J. New.

=*Etheostoma* (*Oligocephalus*) *hopkinsi binotatum* Bailey and Richards.

Etheostoma iowae Jordan and Meek, 1885, Proc. U.S. Nat. Mus., vol. 8, p. 10.

Lectotype: SU 1457 (1, 36), Iowa, Chariton R. at Chariton; D. S. Jordan and S. E. Meek; July–September, 1884; herein selected; one specimen of *E. nigrum* removed and recataloged as SU 62430. D IX–10; A II, 7 or 8; LL 28+31=59, first anal spine much thicker than second; preopercle, opercle, nape, and belly scaled; breast naked.

Paralectotype: The original description was based on three specimens, but we have been unable to locate the third.

=*Etheostoma* (*Oligocephalus*) *exile* (Girard). See Hubbs (1926, p. 66).

Etheostoma (*Nothonotus*) *jordani* Gilbert, 1891, Bull. U.S. Fish Comm., vol. 9, p. 156, pl. 43, fig. 2.

Lectotype: USNM 125110 (♂, 48), Alabama, Calhoun Co., Choccolo Cr. trib. of Coosa R. at Oxford; P. H. Kirsch, W. M. Andrews, and E. O. Jones; May 23, 1889; herein selected. D X–11; A II, 8; LL (right side) 49; INF 8; POM 10; cheeks, prepectoral area, and breast naked; opercles, nape, and belly scaled; no regular longitudinal dark stripes along edges of scale rows.

Paralectotypes: USNM 198107 (8, 27–47), removed from USNM 125110. BMNH 1893.5.5.9–10 (2, 27–39), same data as lectotype. CAS 22854 (4, 24–38), and UMMZ 61706 (♀, 40), same data; orig. IU 4693; badly dried. We have not located the additional syntypes from Chestnut Cr., Verbena, Ala.

=*Etheostoma* (*Nothonotus*) *jordani* Gilbert. See Bailey (1959).

Etheostoma juliae Meek, 1891, Bull. U.S. Fish Comm., vol. 9, p. 130, pl. 42, fig. 2.

Syntypes: USNM 125116 (2 ♂, 41–49) and SU 1010 (♂, 37), Missouri, Greene Co., James R., trib. of White R., near Springfield; S. E. Meek, L. Rettger, and F. M. Drew; July 31, 1889; one of syntypes figured in Jordan and Evermann (1900, fig. 466).

Two topotypes of this species were found with *E. spectabile* (USNM 63366) that were collected with the types of *E. juliae.* They have recataloged as USNM 196750.

=*Etheostoma* (*Oligocephalus*) *juliae* Meek.

Etheostoma lepidogenys Evermann and Kendall, 1894, Bull. U.S. Fish Comm., vol. 12, p. 114, pl. 35.

Syntypes: USNM 44840 (2 ♂, 38–42), Texas, Comal Co., Guadalupe Drainage, Corral Cr. in the largest of the Comal Springs at New Braunfels; B. W. Evermann; Dec. 3, 1891.

=*Etheostoma* (*Oligocephalus*) *lepidum* (Girard).

Etheostoma Linsleyi H. R. Storer, 1851, Proc. Boston Soc. Nat. Hist., vol. 4, p. 37.

Syntypes: New York, Wayne Co., streams at Walcott [now Wolcott], near Lake Ontario; J. H. Linsley. We have been unable to find any type material of this nominal form.

=*Etheostoma* (*Catonotus*) *flabellare flabellare* Rafinesque.

Etheostoma (*Imostoma*) *longimana* Jordan, 1888, Proc. Acad. Nat. Sci. Philadelphia, vol. 40, p. 179.

Lectotype: MCZ 24619 (1, 53), Virginia, trib. of James R., S. F. Baird; about 1855; orig. USNM 1305, then MCZ 150; herein selected by Dr. Charles F. Cole. Anal spines II; LL 44; INF 8; POM 10; supratemporal canal complete; pectoral rays 13–12; scales above lateral line 4; scales below lateral line 8.

Paralectotypes: MCZ 43074 (2, 36–37), removed from MCZ 24619; 5 specimens of *E. nigrum* removed and recataloged as MCZ 42199. USNM 120258 (2, 42–44) and UMMZ 86603 (3, 33–47), same data; previously MCZ 24619; 1 specimen of *E. nigrum* removed from USNM 120258 and recataloged as USNM 197414.

=*Etheostoma* (*Boleosoma*) *longimanum* Jordan.

Etheostoma (*Etheostoma*) *luteovinctum* Gilbert and Swain *in* Gilbert, 1887, Proc. U.S. Nat. Mus., vol. 10, p. 58.

Lectotype: USNM 36139 (1, 37), Tennessee, Stone R., near Nashville; C. H. Gilbert and J. Swain; summer, 1884; herein selected. D IX–13; A II,7; LL 33+17=50; INF barely incomplete, 4+5; POM 10; supratemporal canal complete; cheeks, opercles, and nape fully scaled; breast partially scaled; 6 dorsal saddles.

Paralectotypes: USNM 198003 (2, 33–35), removed from USNM 36139, and SU 3945 (2, 39–40), same data as lectotype.

=*Etheostoma* (*Oligocephalus*) *luteovinctum* Gilbert and Swain.

Etheostoma lynceum Hay *in* Jordan, 1885, Ann. Rept. Comm. Fish and Fish. for 1884, p. 868, a substitute name for *Nanostoma elegans* Hay which is preoccupied in *Etheostoma* by *Boleichthys elegans* Girard.

Types: The types of *E. lynceum* are the same as those of *Nanostoma elegans*, USNM 27445, holotype and SU 627, paratype.

=*Etheostoma* (*Etheostoma*) *zonale lynceum* (Hay), a valid subspecies according to Dr. Chu-fa Tsai (pers. comm.).

Etheostoma macrocephalum Cope, 1869, Trans. Amer. Philos. Soc., new ser., vol. 13, p. 400.

Lectotype: ANSP 22626 (♂, 56), Pennsylvania, Youghiogheny R.; E. D. Cope. This specimen herein selected as the lectotype because it appears to be the only extant syntype. D XIV–12; A II,10; LL about 76; opercle naked; few small scales on cheek posterior to eye; snout long and pointed; eye length longer than snout length.

Fowler (1907) listed ANSP 22626 and 22628 as cotypes. ANSP 22628 (♂, 58) is not part of the type series but a *Percina maculata* with LL 62–64, cheek and opercle completely covered with scales, short blunt snout, eye about equal to snout length. The ANSP catalog lists this specimen as *Alvordius maculatus* from the Kiskiminitas River. Cope based his description on three syntypes, but we have been unable to locate the other two.

=*Percina* (*Alvordius*) *macrocephala* (Cope).

Etheostoma maculata Kirtland, 1841, Boston Journ. Nat. Hist., vol. 3, p. 276, pl. 2, fig. 3.

Types: We have not found any extant type material. Type locality—Mahoning R., Ohio.

=*Etheostoma* (*Nothonotus*) *maculatum maculatum* Kirtland. See Bailey (1959) and Raney and Zorach (MS).

Etheostoma microperca Jordan and Gilbert *in* Jordan, 1888, Manual of the Vertebrates, 5th ed., p. 134, a substitute name for *Microperca punctulatum* (Putnam), preoccupied in *Etheostoma*.

Types: The types of *E. microperca* are the same as those of *Microperca punctulatum* Putnam.

=*Etheostoma* (*Microperca*) *microperca* Jordan and Gilbert.

Etheostoma micropterus Gilbert, 1890, Proc. U.S. Nat. Mus., vol. 13, p. 289.

Holotype: USNM 38245 (♀, 40), Mexico, Chihuahua; E. Wilkinson; figured in Evermann and Kendall (1894, pl. 35) and Jordan and Evermann (1900, fig. 459).

=*Etheostoma* (*Oligocephalus*) *pottsii* (Girard).

Etheostoma (*Nothonotus*) *moorei* Raney and Suttkus, 1964, Copeia, no. 1, p. 131, fig. 1.

Holotype: CU 42883 (♂, 43), Arkansas, Cleburne Co., Devils Fork, 2.5 mi. SW. of Woodrow and 6 airline mi. W. of Drasco; L. W. Knapp and R. V. Miller; Apr. 26, 1962.

Paratypes: CU 41966 (15, 28–42), same data as holotype. USNM 188357 (108, 20–56) and UMMZ 181397 (15, 31–50), type locality; K. Strawn et al.; Aug. 21, 1962. TU 22697 (41, 26–57), Arkansas, Cleburne Co., Devils Fork between Stark and Edgemont on rt. 16; R. D. Suttkus, M. A. Wilkens, and B. I. Sundararaj; Oct. 23, 1959. TU 26227 (22, 27–50), Arkansas, Van Buren Co., Middle Fork at Shirley; Suttkus and W. T. Mason; Aug. 17, 1962. TU 26249 (21, 31–44), Arkansas, Van Buren Co., South Fork, 9 mi. SW. of Clinton on rt. 95; Suttkus and Mason; Aug. 17, 1962. KU 6652 (5, 20–36), Arkansas, Van Buren Co., South Fork of Little Red R. on Ark. 95, approx. 2.5 mi. SW. of Scotland; D. A. Distler and W. N. Berg; Sept. 3, 1960.

=*Etheostoma* (*Nothonotus*) *moorei* Raney and Suttkus.

Etheostoma nevisense Cope, 1870, Proc. Amer. Philos. Soc., vol. 11, p. 261.

Holotype: ANSP ?, (1, ?), North Carolina, falls of Neuse R., 8 mi. E. of Raleigh. Types of other species described by Cope in the 1870 paper were deposited at ANSP, but Fowler (1907) did not mention the type of this form, and we have been unable to find it.

=*Percina* (*Alvordius*) *peltata nevisense* (Cope) according to Dr. Edward C. Raney (pers. comm.).

Etheostoma (*Hadropterus*) *nianguae* Gilbert and Meek *in* Gilbert 1887, Proc. U.S. Nat. Mus., vol. 10, p. 52.

Lectotype: USNM 36214 (♂, 86), Missouri, Webster Co., headwaters of Niangua R., near Marshfield; C. H. Gilbert and S. E. Meek; summer, 1884; listed as type by Jordan and Evermann (1896, p. 1043); selection herein confirmed. D XII–14; A II,12; LL 73; caudal peduncle scale rows 12–2–13.

Paralectotype: SU 5299 (1, 82), same data as lectotype. The original description says deposited in museum of University of Cincinnati, but as Böhlke (1953, p. 73) noted, this specimen bears the proper data and the word "type."

=*Etheostoma* (*Oligocephalus*) *nianguae* Gilbert and Meek. See Kuehne and Bailey (1961).

Etheostoma (*Hadropterus*) *nianguae spilotum* Gilbert, 1887. Proc. U.S. Nat. Mus., vol. 10, p. 53.

Lectotype: USNM 38319 (1, 49), Kentucky, Owsley Co., Sturgeon Cr., trib. of Kentucky R. near Traveler's Rest; C. H. Gilbert; summer, 1884; listed as type by Jordan and Evermann (1896, p. 1044); selection herein confirmed. D X–13; A II,11; LL 50+10=60; caudal peduncle scale rows 10–2–10.

Paralectotypes: SU 4036 (6, 16–67), same data as lectotype; 3 specimens (17–20), apparently *Etheostoma* (*Boleosoma*) sp., removed and recataloged as SU 62429.

=*Etheostoma* (*Oligocephalus*) *sagitta spilotum* Gilbert. See Kuehne and Bailey (1961).

Etheostoma nigra Rafinesque, 1820, Ichthyologia Ohiensis, p. 37.

Types: The original description was based on material from the Green R., Kentucky. As Call (1899) noted, Rafinesque did not preserve any of his type material.

=*Etheostoma* (*Boleosoma*) *nigrum nigrum* Rafinesque.

Etheostoma nuchale Howell and Caldwell, 1965, Tulane Stud. Zool., vol. 12, no. 4, p. 101, fig. 1.

Holotype: UMMZ 187523 (♂, 39), Alabama, Jefferson Co., Glen Spring, Bessemer on Co. rt. 20; W. M. Howell and R. D. Caldwell; Mar. 24, 1964.

Paratypes: UMMZ 187524 (♀, 40, allotype), UMMZ 187525 (20, 27–45), USNM 259800–F 1 (20, 22–48), UAIC 1227 (9, 24–43), same collection as holotype. TU 34591 (20, 17–40), same locality; R. D. Suttkus, J. S. Ramsey, and F. Rose; Sept. 9, 1964.

=*Etheostoma* (*Oligocephalus*) *nuchale* Howell and Caldwell.

Etheostoma obeyense Kirsch, 1892, Bull. U.S. Fish. Comm., vol. 10, p. 292, fig.

Lectotype: USNM 45565 (♂, 52), Kentucky, Clinton Co., trib. of Cumberland R.; P. H. Kirsch; fall, 1889 or spring, 1890; selected and figured by Jordan and Evermann (1896, p. 1092 and 1900, fig. 463); selection herein confirmed.

Paralectotypes: Kirsch collected a total of 210 specimens from four Clinton Co. tributaries of the Cumberland in the fall of 1889 and spring of 1890: Indian Cr., 21; Spring Cr., 36; Smith Cr., 23; and Albany Branch, 130. We have been able to locate the following: SU 5116 (41, 28–51), Albany Branch, 2 *Etheostoma spectabile* removed by Knapp and recataloged as SU 62132. SU 1918 (38, 32–55), Spring Cr. This bottle was broken during the earthquake, which may account for the presence of two more specimens. All are *E. obeyense*, so perhaps Kirsch erred in his count of 36. BMNH 1892.12.30.136–139 (4, 35–41) Albany Branch, one small specimen of *E.* (*Oligocephalus*) *spectabile* removed and recataloged as BMNH 1892.12.30.140.

USNM 46207 (6, 28–43), Wayne Co., Beaver Cr., 1891 were labeled as types but were collected after the types and at a locality not mentioned in the original description and so are not types.

=*Etheostoma* (*Catonotus*) *obeyense* Kirsch.

Etheostoma olmstedi D. H. Storer, 1842, Journ. Boston Soc. Nat. Hist., vol. 4, p. 61, pl. 5, fig. 2.

Syntypes: MCZ 24781 (2♂, 46–64), Connecticut, Connecticut R. at Hartford; C. H. Olmsted; orig. MCZ 151.

=*Etheostoma* (*Boleosoma*) *olmstedi olmstedi* Storer. See Stone (1947) and Cole (1958, 1965). Described in January 1842 and so has priority over *Boleosoma tessellatum* DeKay, July 1842. See Storer (1843) and also summary of the meeting of Boston Society of Natural History for June 21, 1843 (Proc. Boston Soc. Nat. Hist., vol. 1, p. 120).

Etheostoma (*Hadropterus*) *ouachitae* Jordan and Gilbert *in* Gilbert, 1887, Proc. U.S. Nat. Mus., vol. 10, p. 49.

Syntypes: USNM 36449 (2♂, 40–43; ♀, 43), Arkansas, Saline Co., Saline R. at Benton; Jordan and Gilbert; summer, 1884. UMMZ 187509 (1, 42), same data, orig. IU 779, then IU 4958.

Böhlke (1953, p. 74) listed SU 552 [(3, 31–47), Arkansas, Ouachita R. at Arkadelphia; Jordan and Gilbert; summer, 1884] as paratypes, but we do not feel that they should be considered part of the type series because only the Saline River locality was listed, both in the original description and in an advance list (Jordan and Gilbert, 1886, p. 13) where *Hadropterus ouachitae* appeared as a *nomen nudum*.

=*Percina* (*Imostoma*) *uranidea* (Jordan and Gilbert). See Hubbs and Black (1940).

Etheostoma pagei Meek, 1894, Amer. Nat., vol. 27, p. 957.

Lectotype: USNM 45566 (♂, 50); Missouri, spring branch, trib. of Neosho R. at U.S. Fish Hatchery, Neosho; S. E. Meek; Apr. 15, 1893; figured in Jordan and Evermann (1900, fig. 464); herein selected. D IX–12; A II, 7; LL 13+40=53; INF 8; cheeks with small patch of scales; opercles naked; well-developed tubercles on the anal fin characteristic of *E. cragini* (see Collette, 1965).

Paralectotype: USNM 197969 (♀, 40), removed from USNM 45566.

=*Etheostoma* (*Oligocephalus*) *cragini* Gilbert.

Etheostoma (*Oligocephalus*) *pallididorsum* Distler and Metcalf, 1962, Copeia, no. 3, p. 556, fig. 1.

Holotype: KU 7144 (♂, 42), Arkansas, Montgomery Co., Caddo R., 8.5 mi. W. of Black Springs; Sec. 26, T3S, R27W; Distler and Metcalf; June 28, 1961.

Paratypes: KU 6921 (21, 20–42); CU 44004 (10, 23–43), transferred to CU after orig. description; UMMZ 178997 (10, 34–41); USNM 196547 (10, 33–46); same data as holotype. KU 6158 (18, 29–46), Arkansas, Montgomery Co., Caddo R., 1 mi. W. of Caddo

Gap; Distler and Metcalf; Apr. 6, 1961. KU 6922 (8, 32–36), Arkansas, Montgomery Co., trib. of Mill Cr., 2.5 mi. W. of Caddo Gap; Distler and Metcalf; June 29, 1961.

=*Etheostoma* (*Oligocephalus*) *pallididorsum* Distler and Metcalf.

Etheostoma (*Etheostoma*) *parvipinne* Gilbert and Swain *in* Gilbert, 1887, Proc. U.S. Nat. Mus., vol. 10, p. 59.

Holotype: USNM 36716 (1, 43), Alabama, small spring-branch trib. of Black Warrior R. at Tuscaloosa; C. H. Gilbert and J. Swain; summer, 1884.

=*Etheostoma* (*Oligocephalus*) *parvipinne* Gilbert and Swain. See Moore and Cross (1950).

Etheostoma peltatum Stauffer *in* Cope, 1864, Proc. Acad. Nat. Sci. Philadelphia, vol. 16, p. 233.

Holotype: ANSP 22627 (♂, 73), Pennsylvania, Lancaster Co., Conestoga Cr.; J. Stauffer.

=*Percina* (*Alvordius*) *peltata peltata* (Stauffer).

Etheostoma phoxocephalum Nelson, 1876, Bull. Illinois Mus. Nat. Hist., no. 1, p. 35.

Syntypes: UMMZ 187504 (2♂, 49–52), Illinois; S. A. Forbes; orig. IU 499, then IU 4702. Apparently syntypes but not labeled as such or listed in the IU catalog as types. No syntypes are in the collection of the Illinois Natural History Survey according to Smith and Bridges (1960).

=*Percina* (*Swainia*) *phoxocephala* (Nelson). See Bailey (1941).

Etheostoma (*Boleosoma*) *podostemone* Jordan and Jenkins *in* Jordan, 1889, Proc. U.S. Nat. Mus., vol. 11, p. 359, pl. 45, fig. 11.

Lectotype: USNM 39863 (♂, 45), Virginia, Roanoke R. at Allegheny Springs; Jordan and party; summer, 1888; herein selected by Dr. Charles F. Cole. D X–14; A II, 8; LL 38, complete; pectoral 12–12; infraorbital canal complete, 8 pores; preoperculomandibular pores 9; nape, cheeks, breast, and anterior part of belly naked; opercle partially scaled.

Paralectotypes: USNM 197635 (4, 40–45), removed from USNM 39863.

USNM 125477 (3, 26–42), Virginia, Roanoke R. at Roanoke and USNM 40305 (11, 24–41), Virginia, Roanoke R. are listed as paratypes in the U.S. National Museum catalog. Böhlke (1953, p. 74) considered SU 622 (8, 36–45), Virginia, Roanoke R. at Roanoke as paratypes. CAS 22857, formerly IU 7866 (12, 22–44), also from the Roanoke R. at Roanoke are labeled as paratypes. BMNH 1889.10.30.45 (1, 43), Roanoke R., U.S. Fish Comm. is labeled as "one of the types." However, Jordan and Jenkins designated USNM 39863, containing five specimens, as "type," and we believe this to be a designation of these specimens as syntypes from the type locality of Roanoke River at Allegheny Springs. The other specimens should then be considered as material examined and not part of the type series.

=*Etheostoma* (*Boleosoma*) *podostemone* Jordan and Jenkins. See Cole (1958).

Etheostoma quapella Eigenmann and Eigenmann, 1892, Amer. Nat., vol. 26, p. 963. Described in more detail in Eigenmann (1894).

Holotype: BMNH 1892.12.30.183 (♂, 36), Canada, Manitoba, Qu'Apelle R. at Fort Qu'Apelle, Red R. system; C. H. Eigenmann; August-September 1892.

=*Etheostoma* (*Oligocephalus*) *exile* (Girard). See Jordan and Evermann (1896) and Hubbs (1926, p. 68).

Etheostoma (*Percina*) *rex* Jordan and Evermann *in* Jordan, 1889, Proc. U.S. Nat. Mus., vol. 11, p. 357, pl. 45, fig. 9.

Holotype: USNM 39858 (♂, 122), Virginia, Roanoke R., near Roanoke; Jordan; summer, 1888.

Paratype: Jordan and Evermann mentioned a second smaller specimen taken with the type, but the whereabouts of this specimen is unknown.

=*Percina* (*Percina*) *rex* (Jordan and Evermann).

Etheostoma (*Hadropterus*) *roanoka* Jordan and Jenkins *in* Jordan, 1889, Proc. U.S. Nat. Mus., vol. 11, p. 358, pl. 45, fig. 10.

Lectotype: USNM 39866 (♂, 48), Virginia; Roanoke R. at Allegheny Springs; Jordan and party; summer, 1888. USNM 39866, then containing at least five specimens, given as "type" in original description; one specimen herein selected as lectotype by Dr. Edward C. Raney. D XI–12; A II,9; LL 47; cheeks naked; breast naked except for one large modified scale; nape naked anteriorly, with a few scales posteriorly; opercles with scales at least on upper portion; suborbital bar prominent; sides with 10 vertical bars tending to form a lateral band.

Paralectotypes: USNM 197774 (4 ♂, 43–48), removed from USNM 39866. MCZ 3106 (♂, 40); CU 46469 (3, 43–48); CU 46470 (1, 48), found with CU 46469 but probably out of MCZ 3106; SU 616 (9, 41–53), one specimen of *Percina peltata* removed; and UMMZ 187514 (7, 24–45), orig. IU 1143, then IU 5619, listed in old IU catalog as type, one specimen of *Etheostoma podostemone* removed and recataloged as UMMZ 187515; all from Roanoke R. at Roanoke.

In addition to the collections from the Roanoke River at Roanoke and Allegheny Springs listed above, specimens from two other rivers are mentioned in the original description. We feel that only the specimens from the Roanoke River should be considered as types, because Jordan and Jenkins designated a Roanoke series as "type," and because they specifically mentioned that the North Carolina specimens had larger scales than the Roanoke material. Therefore, we consider the following specimens from the Neuse and Tar rivers in North Carolina as other material, not as types. SU 17777 (1, 48), North Carolina, Neuse R. at Raleigh; listed by Böhlke (1953, p. 74) as a paratype. USNM 125359 (1, 42), same data; listed as a paratype in the USNM catalog. USNM 40367 (13, 29–48) and ANSP 70743–4 (2, 33–38), out of USNM 40367; same data, not listed as type in USNM catalog. UMMZ 187516 (♂, 59), orig. IU 1158, then IU 7998, part of the same series from the Neuse R.; not listed as type in IU catalog. UMMZ 187517 (1, 33), North Carolina, Tar R. at Rocky Mount; orig. IU 1144, then IU 7888, not listed as type in IU catalog; two specimens of *Percina peltata* removed and recataloged as UMMZ 187518.

=*Percina (Ericosma) crassa roanoka* (Jordan and Jenkins), according to Dr. Edward C. Raney (pers. comm.).

Etheostoma (*Rhothoeca*) *rupestre* Gilbert and Swain *in* Gilbert, 1887, Proc. U.S. Nat. Mus., vol. 10, p. 57.

Lectotype: USNM 36695 (♀, 32), Alabama, North R., trib. of Black Warrior R., near Tuscaloosa; C. H. Gilbert and J. Swain; summer, 1884; herein selected by Dr. Chu-fa Tsai. D XI–12; A II,7; LL 52; INF 4+3; POM 9; cheeks and breast naked; opercle with 2 imbedded scales; belly scaled anteriorly; 6 dorsal blotches.

Paralectotypes: USNM 188971 (17, 23–34), removed from USNM 36695.

=*Etheostoma* (*Etheostoma*) *rupestre* Gilbert and Swain.

Etheostoma sciotense Osburn and Williamson, 1898, Ann. Rept. Ohio State Acad. Sci., vol. 6, p. 17.

Lectotype: USNM 48846 (♂, 29), Ohio, Franklin Co., Big Walnut Cr., trib. of Scioto R., near Columbus; B. C. Osburn and E. B. Williamson; June 26, 1897; herein selected. D XII–12; A II,7; LL 27+19=46; anterior third of belly naked.

Paralectotypes: USNM 197995 (♂, 24), removed from USNM 48846. A third syntype was deposited in Jordan's collection, but we have been unable to find this specimen.

=*Etheostoma* (*Nothonotus*) *tippecanoe* Jordan and Evermann. See Osburn and Williamson (1899).

Etheostoma scovellii Woolman, 1892, Amer. Nat., vol. 26, p. 260.

Lectotype: USNM 44155 (1, 33), Mexico, Río de las Conchos, Chihuahua; A. J. Woolman; August 1891; herein selected. D XI–11;

A I,7; LL 44+15=59; INF 8; interorbital pores 2; cheeks, opercles, nape, and breast naked.

Paralectotypes: USNM 197970 (2, 27–34), out of USNM 44155. BMNH 1892.12.30.186–188 (3, 29–32), same data. CAS 22856 (3, 20–25), same data; orig. IU 4841.

=*Etheostoma* (*Austroperca*) *australe* Jordan. See Hubbs (1936).

Etheostoma (*Hadropterus*) *squamatus* Gilbert and Swain *in* Gilbert, 1887, Proc. U.S. Nat. Mus., vol. 10, p. 50.

Holotype: USNM 36652 (♂, 85), Tennessee, French Broad R. at mouth of Wolf Cr.; C. H. Gilbert and J. Swain; summer, 1884.

=*Percina (Swainia) squamata* (Gilbert and Swain).

Etheostoma squamiceps Jordan, 1877, U.S. Nat. Mus. Bull. 10, p. 11.

Lectotype: USNM 1145 (♂, 57), Kentucky, Logan Co., Russellville; Bebb; erroneously given as USNM 1345 in orig. description; herein selected. D IX–13; A II,7; LL 45+3=48; POM 10; INF incomplete; cheek and opercle covered with scales; small unpigmented fleshy bulbs around tips of first dorsal spines.

Paralectotype: USNM 197968 (♀, 54) removed from USNM 1145.

=*Etheostoma* (*Catonotus*) *squamiceps* Jordan. See Moore and Cross (1950, p. 145).

Etheostoma (*Nanostoma*) *swannanoa* Jordan and Evermann *in* Jordan, 1889, Proc. U.S. Nat. Mus., vol. 11, p. 360, pl. 45, fig. 13.

Lectotype: USNM 39861 (♀, 59), Virginia, S. Fork of Holston R. at Holstein Mills; D. S. Jordan and B. W. Evermann; summer, 1888; USNM 39861 given as type by Jordan and Evermann but then containing two specimens; lectotype herein selected by Dr. William J. Richards. D XII–12; A II,9; pectoral 16–16; LL 57; INF 8; POM 10; head, cheeks, opercles, and breast naked; vomerine teeth present; palatine teeth absent.

Paralectotypes: USNM 196777 (♀, 56), removed from USNM 39861. Jordan and Evermann designated USNM 39861 as "type," but they gave counts of the lateral line scales in 8 of the 10 specimens they had before them. Therefore, their description was apparently based on all their material, and the following are also considered paralectotypes. USNM 125490 (♀, 40), North Carolina, S. Fork of Swannanoa R. at Black Mountain; Jordan and Evermann; August 1888; orig. BF 772. SU 3507 (♀, 41), same locality as USNM 125490. Böhlke (1953, p. 74) gave the same data for SU 992 (2 ♂, 54–57) as for USNM 39861, but Jordan and Evermann reported only two specimens from this locality, so it seems likely that SU 992 is from Middle Fork of Holston R. at Marion or S. Fork of Swannanoa R. at Black Mountain. UMMZ uncat. (♂, 49), orig. IU 1169, then IU 8083. Locality in IU catalog for IU 8083 is N. Fork of Holston R. at Saltville, Va., but

Jordan and Evermann did not report this species from there. Locality in the IU catalog for 1169 is apparently S. Fork of Holston R. at Holstein Mills, Va. However, as with SU 992, this specimen must be from Middle Fork of Holston R. at Marion or S. Fork of Swannanoa R. at Black Mountain.

=*Etheostoma* (*Etheostoma*) *swannanoa* Jordan and Evermann.

Etheostoma tessellata D. H. Storer, 1845, Proc. Boston Soc. Nat. Hist., vol. 2, p. 48. Original description repeated almost verbatim in Storer (1846).

Syntypes: Alabama, Florence; received from C. A. Hentz. We have been unable to find any type material of this nominal form.

=?*Percina* (*Ericosma*) *evides* (Jordan and Copeland) according to Bailey (1959, p. 2). Although *E. tessellata* Storer is a senior synonym of *Alvordius evides* Jordan and Copeland, 1877, it is not available because *tessellata* is preoccupied in *Etheostoma* by *Boleosoma tessellatum* DeKay, 1842.

Etheostoma tippecanoe Jordan and Evermann, 1890, Proc. U.S. Nat. Mus., vol. 13, p. 3 [with fig. of *E. camurum*].

Lectotype: USNM 40080 (1, 29), Indiana, Tippecanoe R. at Marshland; B. W. Evermann; herein selected. D XII–13; A II, 8; LL 37+16=53; cheeks, prepectoral area, nape, and breast naked; opercle scaled; anterior part of belly naked along midline.

Paralectotype: USNM 197919 (1, 26), out of USNM 40080.

Four specimens are mentioned in the original description of *E. tippecanoe*. The two USNM specimens fit the original description and the current concept of *E. tippecanoe*. The other two syntypes apparently are UMMZ 187513 (2, 29–44), orig. IU 1194, then IU 4688. They have the belly completely scaled and lateral line scale counts of about 54+0=54 and 66+1=67. The larger one is a specimen of *E. camurum* and the smaller one probably is also. Jordan and Evermann (1896, p. 1090) wrote that the original description of *E. tippecanoe* was accompanied by a figure of *E. camurum* "by an error of printer." We believe that the specimen figured in Jordan and Evermann is the smaller specimen in UMMZ 187513. We count the same number of lateral line scales on the figure and the small specimen. The original drawing is labeled as a specimen 1 7/16 in. long (total length) from no. 40080. This is equal to a standard length of about 29 mm. Three sets of comments are written on the original drawing. "The drawing is bad, but it was made from specimens sent to the National Museum as types of *E. tippecanoe*." "This is probably *E. camurum*. Certainly not *E. tippecanoe*. Anal fin very bad." "Fearful and not taken from our type."

=*Etheostoma* (*Nothonotus*) *tippecanoe* Jordan and Evermann. See Bailey (1959).

Etheostoma (*Psychromaster*) *trisella* Bailey and Richards, 1963, Occ. Pap. Mus. Zool. Univ. Michigan, no. 630, pl. 1, D–E.

Holotype: UMMZ 180073 (1, 35), Alabama, Cherokee Co., Cowans Cr., trib. of Spring Cr. which flows into Coosa R. at Jordans Farm on U.S. 411, 6.7 mi. SE. of Centre; E. A. Lachner and P. S. Handwerk; Sept. 13, 1947; orig. CU 18579.

=*Etheostoma* (*Psychromaster*) *trisella* Bailey and Richards.

Etheostoma (*Etheostoma*) *tuscumbia* Gilbert and Swain *in* Gilbert, 1887, Proc. U.S. Nat. Mus., vol. 10, p. 63.

Syntypes: SU 1003 (30, 25–48) and BMNH 1894.5.18.26–27 (2, 28–31), large spring at Tuscumbia flowing into Tennessee R.; C. H. Gilbert and J. Swain; summer, 1884; one of types figured by Jordan and Evermann (1900, fig. 467). Apparently UMMZ 187512 (44, 22–35), orig. IU 1380, then IU 5666, specimens almost completely disintegrated, are also syntypes, although they are not listed as types in the IU catalogs.

USNM 36154 with the same data also originally contained syntypes. This jar was found completely dried out in March 1937 and only fragments now remain. We believe that not many specimens were in the jar at that time because old correspondence of Barton Bean shows that at least 37 specimens from this series were sent out as "duplicate sets" to 37 high schools and other such institutions during the period Aug. 4, 1902 to Dec. 12, 1903. We assume that Bean was unaware that USNM 36154 contained types, for he certainly would not have sent type material to such institutions as the public schools of Kent, Wis.; Omaha, Nebr.; Windfall, Ind.; Galliopolis, Ohio; Helena, Mont.; Savanna, Ill.; Northwood, Iowa; Lovington, Ill.; Wiconisco, Pa.; the Free Public Library of Vinton, Iowa; the San Antonio Female College, Tex.; and the Ursuline Seminary, New Rochelle, N.Y.!

Böhlke (1953) and Bailey and Richards (1963) gave USNM 36154 as holotype. Böhlke listed SU 1003 as paratypes. From the number of specimens distributed out of USNM 36154, it is clear that all of the original type material should be listed as syntypes.

Böhlke erroneously listed SU 2683 (2, 27–28) as paratypes, but these specimens were collected at Florence, Ala., a locality not mentioned in the original description. Bailey and Richards (1963) listed USNM 43484 and 63115 and UMMZ 43484 as paratopotypes, but this material was collected by Kirsch in 1889, subsequent to the original description of *E. tuscumbia*, and so they are merely topotypes.

=*Etheostoma* (*Psychromaster*) *tuscumbia* Gilbert and Swain. See Bailey and Richards (1963).

Etheostoma (*Cottogaster*) *uranidea* Jordan and Gilbert *in* Gilbert, 1887, Proc. U.S. Nat. Mus., vol. 10, p. 48.

Syntypes: USNM 36413 (8, 31–46), Arkansas, Washita (Ouachita) R. at Arkadelphia; Jordan and Gilbert; summer, 1884. One specimen of *Etheostoma histrio* removed and recataloged as USNM 197419.

=*Percina* (*Imostoma*) *uranidea* (Jordan and Gilbert).

Etheostoma variata Kirtland, 1841, Boston Journ. Nat. Hist., vol. 3, p. 274, pl. 2, fig. 2.

Types: Type locality—Mahoning R., Ohio. We have been unable to find any extant type material.

=*Etheostoma* (*Etheostoma*) *variatum* Kirtland.

Etheostoma (*Ulocentra*) *verecundum* Jordan and Evermann *in* Jordan, 1889, Proc. U.S. Nat. Mus., vol. 11, p. 360, pl. 45, fig. 12.

Holotype: USNM 39862 (1, 44), Virginia, Middle Fork of Holston R., 5 mi. S. of Glade Spring; summer, 1888.

=*Etheostoma* (*Ulocentra*) *simoterum* (Cope).

Etheostoma (*Etheostoma*) *whipplei alabamae* Gilbert and Swain *in* Gilbert, 1887, Proc. U.S. Nat. Mus., vol. 10, p. 62.

Syntypes: USNM 36735 (6, 25–30), Alabama, Black Warrior R., near Morris; C. H. Gilbert and J. Swain; summer, 1884. USNM 36687 (2, 29–41), and SU 2318 (2, 35–41), Alabama, North R., trib. of Black Warrior R., near Tuscaloosa; Gilbert and Swain; summer, 1884.

=*Etheostoma* (*Oligocephalus*) *whipplii artesiae* (Hay). See Hubbs and Black (1941).

Etheostoma wrighti McCormick, 1892, Bull. Oberlin College Lab., no. 2, p. 30.

Holotype: Oberlin Coll. Mus. (1, 2⅝ in.), Ohio, Lorain Co., Vermillion R., trib. of Lake Erie; L. M. McCormick; Apr. 9, 1892. This specimen was not present in the Oberlin collection in mid-January 1931, according to Trautman (1957, p. 548), and has not been located.

=*Percina* (*Imostoma*) *shumardi* (Girard), according to Jordan and Evermann (1896, p. 1047) and Jordan, Evermann, and Clark (1930, p. 285). The type locality and original description support this conclusion, but Trautman (1957, p. 548) has suggested that *E. wrighti* may be a hybrid between *P. shumardi* and *P. caprodes* or *P. maculata*, or between *P. caprodes* and *P. maculata*.

Etheostoma zonale arcansanum Jordan and Gilbert, 1886, Proc. U.S. Nat. Mus., vol. 9, p. 5.

Lectotype: USNM 36410 (♀, 38), Arkansas, Washita (Ouachita) R. at Arkadelphia; D. S. Jordan and C. H. Gilbert; summer, 1884; herein selected by Dr. Chu-fa Tsai. D XI–11; A II,7; LL 56; INF 4+3; POM 10; cheeks, opercles, and belly completely covered with scales; a few scales on breast; 6 dorsal blotches.

Paralectotypes: USNM 188970 (25, 24–36), removed from USNM 36410. UMMZ 187506 (7, 25–36), orig. IU 777, then IU 4543, same data. USNM 36249 (2, 40–43), Missouri, Spring Fork of Neosho R., near Carthage; Gilbert and S. E. Meek. USNM 36275 (1, 41), Missouri, James Fork of White R., near Marshfield; Gilbert and Meek. USNM 36399 (2, 30–31), Oklahoma, Poteau R., W. of Hackett City, Ark.; Jordan and Gilbert; summer, 1884. USNM 36447 (15, 21–35), Arkansas; Saline R., near Benton, just above railroad bridge; Jordan and Gilbert; summer, 1884; six specimens of *Etheostoma r. radiosum* removed. UMMZ 187507 (4, 22–29), same locality, orig. IU 779, then IU 4546; one specimen of *E. histrio* removed and recataloged as UMMZ 187508.

=*Etheostoma* (*Etheostoma*) *zonale zonale* (Cope), according to Dr. Chu-fa Tsai (pers. comm.).

Hadropterus evermanni Moenkhaus, 1903, Bull. U.S. Fish Comm., vol. 22, p. 397, fig.

Holotype: Given as IU 9785 (1, 77), Indiana, Lake Tippecanoe in original description, but we have not located this specimen.

Paratypes: USNM 50834 (1, 48) and USNM 126919 (1, 48); 1899; orig. BF 2742; Lake Tippecanoe. We have not found the paratype originally cataloged as IU 9786 nor the specimen said to have been deposited at Stanford University. There appears to be no record of a paratype having been deposited in the British Museum, and Collette could find none among the type material or in the regular collections in October 1963.

=*Percina* (*Percina*) *caprodes semifasciata* (DeKay) × *Percina* (*Alvordius*) *maculatus* (Girard). See Hubbs (1926, p. 60). The two USNM specimens and the figure of the holotype appear to be intermediate between *P. caprodes* and *P. maculatus* in such characters as color pattern, number of lateral line scales, juncture of gill membranes, nape squamation, and snout shape. Trautman (1948) has also reported this natural hybrid combination from southwestern Lake Erie and tributaries that enter the lake in this region.

Hadropterus maculatus Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 100.

Lectotype: USNM 1157 (♂, 69), Maryland, Anne Arundel Co., eastern trib. of Potomac R.; J. H. Clark; selected herein by Dr. Edward C. Raney. D XIV–12; A II,9; pectoral rays 14–13; LL 55;

scales above and below lateral line 7–10; caudal peduncle scales 21; cheeks sparsely scaled; opercles scaled; preopercles and nape naked; 11 enlarged scales on midline of belly. This specimen is also the type of *Hadropterus notogrammus* Raney and Hubbs.

Paralectotype: USNM 197773 (♂, 56) removed from USNM 1157.

MCZ 24525 (2 ♂, 60–64), originally USNM 1303, then MCZ 129, and MCZ 24546 (2 ♂, 54–55), originally USNM 1157, then MCZ 130, have the same data and were probably part of the original series; however, they were received from the USNM in 1853, but the description was not published until 1859, so it is doubtful if Girard had the specimens before him at the time of the original description. Therefore, the four specimens had best be considered only as topotypes, both of *H. maculatus* Girard and *H. notogrammus* Raney and Hubbs.

=*Percina* (*Alvordius*) *notogramma notogramma* (Raney and Hubbs) because *maculatus* is preoccupied by *Alvordius maculatus* Girard. See Hogarth and Woolcott (1966).

Hadropterus maxinkuckiensis Evermann, 1900, Rept. U.S. Fish Comm., vol. 25., p. 366, pl. 17.

Holotype: USNM 49378 (♂, 75), Indiana, Marshall Co., Aubeenaubee Cr., E. inlet of L. Maxinkuckee, 0.5 mi. from lake; Evermann and Scovell; Aug. 4, 1899.

=*Percina* (*Alvordius*) *maculata* (Girard). See Hubbs and Black (1954).

Hadropterus nasutus Bailey, 1941, Occ. Pap. Mus. Zool. Univ. Michigan, no. 440, figs. 1, 3.

Holotype: UMMZ 132898 (♂, 66), Arkansas, Searcy Co., Middle Fork, Little Red R., trib. of White R., near bridge on U.S. 65, 1.5 mi. SE. of Leslie; R. M. Bailey and M. E. Davis; Aug. 17, 1940.

Paratype: USNM 198146 (♀, 63), same data as holotype; orig. ISC 2.

=*Percina* (*Swainia*) *nasuta* (Bailey).

Hadropterus nigrofasciatus Agassiz, 1854, Amer. Journ. Sci. and Arts, ser. 2, vol. 17, p. 305.

Lectotype: MCZ 24603 (♂, 103), Alabama, near Mobile, A. Stein; orig. out of USNM 1197, then MCZ 122; herein selected. D XII–12; A II, 9; LL 50; preopercle without serrae; branchiostegal membranes slightly connected; nape, cheek, opercle, and breast completely scaled.

Paralectotypes: MCZ 43094 (11, 41–98) and UMMZ 86300 (3, 51–77), removed from MCZ 24603. USNM 1197 (♂, 74; ♀, 82), same data.

=*Percina* (*Hadropterus*) *nigrofasciata nigrofasciata* (Agassiz). See Crawford (1956).

Hadropterus nigrofasciatus westfalli Fowler, 1942, Notulae Naturae, no. 107, p. 9, fig. 9.

Holotype: ANSP 69980 (♂, 44), Florida, Wekiva R., trib. of St. Johns R.; M. J. Westfall, Jr.; Mar. 8, 1941.

=*Percina* (*Hadropterus*) *nigrofasciata nigrofasciata* (Agassiz). See Crawford (1956).

Hadropterus notogrammus Raney and Hubbs, 1948, Occ. Pap. Mus. Zool. Univ. Michigan, no. 512, pl. 1, figs. 1–2; pl. 2, figs. 1–2; a replacement name for *Hadropterus maculatus* Girard which was preoccupied.

Types: Raney and Hubbs designated UMMZ 144696 [(♂, 67), Virginia, Rockbridge Co., South R., 5 mi. E. of Lexington, L. C. Pettit; May 17, 1941; orig. CU 9719] as holotype; and USNM 40242; CU 8324, 9708, 10138, 4909; UMMZ 144697 and 95194 as paratypes. However, these designations are not valid because the type specimens for a new name must be the same as for the original name (Art. 72 d, Int. Code Zool. Nomencl.), in this case USNM 1157, lectotype and USNM 197773, paralectotype of *Hadropterus maculatus* Girard.

=*Percina* (*Alvordius*) *notogramma notogramma* (Raney and Hubbs). See Hogarth and Woolcott (1966).

Hadropterus oxyrhynchus Hubbs and Raney, 1939, Occ. Pap. Mus. Zool. Univ. Michigan, no. 396; pl. 1.

Holotype: UMMZ 118422 (♂, 80), West Virginia, Randolph Co., Cheat R. at Cheat Bridge; E. C. Raney; June 25, 1935.

Paratypes: USNM 56862 (♂, 63), West Virginia, Cheat R. at Raines; W. P. Hay; Sept. 12, 1899. UMMZ 118482 (4, 44–54), Virginia, Wythe Co., New R., above Jacksons Ferry; C. L. Hubbs and family; Aug. 21, 1936. UMMZ 119268 (7, 20–33), West Virginia, New R. at Prince; J. Addair; July 26, 1935. UMMZ 119246 (2, 30–31), West Virginia, New R., 2 mi. below Hinton; Addair; July 18, 1935.

=*Percina* (*Swainia*) *oxyrhyncha* (Hubbs and Raney). See Bailey (1941).

Hadropterus palmaris Bailey, 1940, Journ. Washington Acad. Sci., vol. 30, no. 12, p. 525, fig. 1.

Holotype: UMMZ 126179 (♂, 66), Georgia, Lumpkin Co., Etowah R., trib. of Coosa R., just above bridge on U.S. 19, 4 mi. SW. of Dahlonega; R. M. and M. K. Bailey; Aug. 25, 1939.

Paratypes: UMMZ 126180 (2, 45–67), USNM 117881 (2 ♂, 61–68) and USNM 198145 (♂, 63), orig. ISC 1, same data as holotype. UMMZ 111232 (1, 59) and UMMZ 111133 (22, 31–63), Alabama, Saugahatchee Cr., trib. of Tallapoosa R.; F. E. Guyton; Oct. 24,

1930. UMMZ 111234 (4), Alabama, Macon Co., 3 mi. E. of Tuskegee; Guyton; June 3, 1931; there is a note in the UMMZ card file that these specimens were not located during a check several years ago, and we were unable to find them in May 1964.

=*Percina* (*Ericosma*) *palmaris* (Bailey). See Crawford (1954).

Hadropterus pantherinus Moore and Reeves, 1955, Copeia, no. 2, p. 90, pl. 1.

Holotype: UMMZ 167120 (♀, 63), Oklahoma, Pushmataha Co., Little R., W. of Pickens, sec. 1, T. 2 S., R. 20 E.; G. A. Moore and J. D. Reeves; Mar. 25, 1951.

Paratypes: UMMZ 81185 (1, 59), Arkansas, Polk Co., trib. of Mountain Fork R.; June 29, 1927; Univ. Oklahoma Mus. Exped. OAM 2559 (1, 38), Oklahoma, McCurtain Co., Mountain Fork R., Beavers Bend State Park, sec. 10, T. 5 S., R. 25 E.; Moore and class; Aug. 21, 1948. UMMZ 167122 (3, 22–27), same locality as OAM 2559, Moore and F. B. Cross; May 30, 1948. USNM 198108 (1, 35), Oklahoma, LeFlore Co., Little R., S. of Honobia, sec. 30, T. 1 N., R. 22 E.; A. P. Blair; orig. TUC uncat. MCZ 38491 (1, 41), Oklahoma, McCurtain Co., Mountain Fork R. at Smithville, sec. 13, T. 1 S., R. 25 E.; Moore and C. C. Rigney; Aug. 17–19, 1948. UMMZ 167121 (6, 48–72), same locality as UMMZ 167120; Moore and Reeves; Mar. 25, 1951. OAM 4948 (1, 52), Oklahoma, McCurtain Co., Glover R. in sec. 13, T. 3 S., R. 22 E.; Moore and Reeves; Mar. 25, 1951.

=*Percina* (*Alvordius*) *pantherina* (Moore and Reeves).

Hadropterus scierus Swain, 1883, Proc. U.S. Nat. Mus., vol. 6, p. 252.

Lectotype: USNM 34350 (♂, 57), Indiana, Monroe Co., Bean Blossom Cr., trib. of White R., 6 mi. N. of Bloomington; D. S. Jordan and J. Swain; herein selected. D XIII–14; A II,10; LL complete, 71; preopercle serrate; branchiostegal membranes moderately joined.

Paralectotypes: Two specimens were mentioned in the original description, but we do not know if the second syntype is still in existence.

=*Percina* (*Hadropterus*) *sciera sciera* (Swain). See Hubbs and Black (1954).

Hadropterus scierus apristis Carl L. Hubbs and Clark Hubbs *in* Clark Hubbs, 1954, Amer. Mid. Nat., vol. 52, no. 1, p. 211.

Holotype: UMMZ 162377 (♂, 68), Texas, Caldwell-Guadalupe cos., San Marcos R., 0.5 mi. SE. of Prairie Lea; K. C. Jurgens and R. C. MacEwan; Feb. 11, 1950.

Paratypes: UMMZ 162378 (40, 46–74), same data as holotype. USNM 160628 (6 ♀, 48–61; 5 ♂, 57–83), Texas, Caldwell-Guadalupe cos., San Marcos R. at Stairtown; Jurgens and MacEwan; Feb. 18, 1950, orig. TNHC 255. USNM 160629 (11 ♀, 50–69, 1 ♂, 73), Texas, Caldwell-Guadalupe cos., San Marcos R., 0.5 mi. S. of Prairie Lea; Jurgens and W. Brown; Feb. 8, 1950; orig. TNHC 180. UMMZ 162374 (9, 41–72), Texas, Hays Co., San Marcos R., below cotton gin near State Fish Hatchery; C. Hubbs and Jurgens; Sept. 26, 1949; orig. TNHC 21. FMNH 46194 (13, 27–64), Texas, San Marcos R., 3 mi. SE. of State Fish Hatchery; Jurgens and Hubbs; Sept. 26, 1949; orig. TNHC 40; specimens partly dried out; erroneously given as FMNH 46195 in original description. OAM 4707 (8, 42–63), Texas, Caldwell-Guadalupe cos.; San Marcos R. at Fentress; Jurgens and Brown; Nov. 18, 1949. TNHC 90 (15, 28–56), Texas, Caldwell-Guadalupe cos.; San Marcos R., 0.5 mi. N. of Staples; Jurgens; Nov. 11, 1949. TNHC 501 (1, 75), Texas, Gonzales Co., Guadalupe R. at rt. 80, S. of Belmont; Hubbs; Apr. 6, 1950. TNHC 162 (1, 76), Texas, Gonzales Co., Guadalupe R., ¼ mi. SE. of Gonzales; Jurgens. TNHC 314 (1, 66), Texas, Comal Co., Guadalupe R. at Hunter; Jurgens and Brown; Mar. 22, 1950. SU 17311 (3), Texas, Caldwell-Guadalupe cos.; San Marcos R. at Stairtown; Mar. 25, 1950; Jurgens and W. Faber; orig. TNHC 333; specimens now completely disintegrated. TAMC 1F–13–g–10 (16, 35–78), Texas, Caldwell-Guadalupe cos., San Marcos R. at Martindale; Jurgens and Brown; Nov. 6, 1949. TAMC 1F–13–g–4 (1, ?), Texas, Gonzales Co., Guadalupe R., 0.5 mi. S. of Gonzales; F. T. Knapp; Nov. 26, 1950; dried out.

=*Percina* (*Hadropterus*) *sciera apristis* (Hubbs and Hubbs).

Hadropterus scierus serrula Jordan and Gilbert, 1886, Proc. U.S. Nat. Mus., vol. 9, p. 16.

Lectotype: USNM 36481 (♂, 50), Texas, Sabine R., 5 mi. S. of Longview; D. S. Jordan and C. H. Gilbert; summer, 1884; herein selected. D XII–14; A II,9; LL complete, 65; preopercular serrae 10–13.

Paralectotypes: USNM 198010 (5, 43–47), removed from USNM 36481.

Jordan and Gilbert had other material of their new variety from the Trinity River at Dallas, Tex. (USNM 36476) and from the Rio Lampasas at Belton, Tex. Evermann and Kendall (1894, pp. 88, 113) gave the type locality as the Sabine River at Longview. Jordan and Evermann (1896, p. 1038) gave the "type" as USNM 36481 and the type locality as the Red River at Fulton, Ark. Hubbs and Black (1954, p. 205) pointed out that Jordan and Evermann did not collect *serrula* in the Red River and no. 36481 is from the Sabine. Hubbs and Black designated USNM 36481 "as the sole lectotypes." We feel that Jordan and Evermann meant USNM 36481 to be the "types" in the first place, so Hubbs and Black's action was not necessary. Böhlke (1953, p. 74) listed SU 3934 from Rio Lampasas as paratypes and USNM 36481 as holotype. SU 3934 cannot be paratypes because USNM 36481 from the Sabine contains the entire type series as originally indicated by Jordan and Gilbert and confirmed by Evermann and Kendall (1894), Jordan and Evermann (1896), and Hubbs and Black (1954).

=*Percina* (*Hadropterus*) *sciera* ssp. Further study is necessary to determine whether or not *serrula* can be recognized as a valid subspecies. See Hubbs and Black (1954) and Hubbs (1954).

Hadropterus sellaris Radcliffe and Welsh, 1913, Bull. U.S. Bur. Fish., vol. 32, p. 31, pl. 18.

Holotype: USNM 74346 (♀, 39), Maryland, Harford Co., Swan Cr., near Havre de Grace; L. Radcliffe and W. W. Welsh; May 2, 1912.

Paratype: USNM 74347 (♀, 39), same data as holotype.

=*Etheostoma* (*Etheostoma*) *sellare* (Radcliffe and Welsh). See Hubbs and Black (1940) and Knapp et al. (1963).

Hadropterus shumardi Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 100.

Holotype: USNM 1330 (♂, 48), Arkansas, Arkansas R., near Ft. Smith; G. C. Shumard.

=*Percina* (*Imostoma*) *shumardi* (Girard).

Hadropterus spillmani Hay, 1881, Proc. U.S. Nat. Mus., vol. 3, p. 491.

Lectotype: USNM 27432 (♂, 64), Mississippi, Clarke Co., Chickasawha R. at Enterprise; O. P. Hay; March–April 1880; listed as type by Jordan and Evermann (1896, p. 1039); selection herein confirmed. D XII–12; A II,9; pectoral 14–15; LL 54; scales above and below lateral line 6–11; cheeks, opercles, breast, and nape completely covered with scales; several serrations on preopercle.

Paralectotypes: The original description was based on "several specimens" of which some were placed "in Professor Jordan's collection" and the remainder in Butler University. These specimens are apparently no longer in existence.

=*Percina* (*Hadropterus*) *nigrofasciata nigrofasciata* (Agassiz). See Crawford (1956, p. 41).

Hadropterus tessellatus Jordan, 1877, U.S. Nat. Mus. Bull. 10, p. 7.

Lectotype: USNM 1199 (1, 47), Pennsylvania, Allegheny R. at Foxburg; S. F. Baird; herein selected. D XIII–12; A II,9; LL 51; pectoral rays 16; INF 8, fourth pore opening at the end of a dorsally directed tube beneath the eye; POM 10; four blackish dorsal saddles; cheeks naked; opercles and breast with few scales.

Paralectotype: USNM 197416 (1, 29), removed from USNM 1199. This smaller specimen was found in the bottle labeled USNM 1199. This might not be part of the type material because Jordan referred to "a specimen of an Etheostomoid" and "length of type 2½ inches" and so may have examined only the larger specimen. However, Jordan (1885, p. 163) mentioned two specimens as "the types of *Hadropterus tessellatus*."

=*Etheostoma* (*Etheostoma*) *variatum* Kirtland. See Jordan (1885) and Hubbs and Black (1941, p. 15).

Hololepis barratti appalachia J. R. Bailey, 1950, Copeia, no. 4., p. 312.

Holotype: UMMZ 156224 (♂, 37), North Carolina, Buncombe Co., pond S. of mouth of Bent Cr., 300 ft. W. of French Broad R., 7 mi. SSW. of Asheville; F. Cross and Y. Barber; July 14, 1947.

Paratypes: UMMZ 156225 (48, 13–42), same data as holotype. CU 18444 (3, 30–40), and DU uncat. (6♀, 19–40), same locality; June 7, 1949; J. R. Bailey.

=*Etheostoma* (*Hololepis*) *fusiforme barratti* (Holbrook). See Collette (1962).

Hololepis collis Hubbs and Cannon, 1935, Misc. Publ. Mus. Zool. Univ. Michigan, no. 30, p. 52, pl. 1, fig. 7.

Holotype: UMMZ 94560 (♂, 40), South Carolina, York Co., creek near York; D. Ameel; Nov. 11, 1931.

Paratypes: UMMZ 107085 (♀, 40), same data as holotype. UMMZ 94546 (♂, 36), South Carolina, York Co., Steel Cr., trib. of Catawba R. at Rock Hill; Ameel; Nov. 11, 1931.

=*Etheostoma* (*Hololepis*) *collis collis* (Hubbs and Cannon). See Collette (1962).

Hololepis erochrous Cope, 1864, Proc. Acad. Nat. Sci. Philadelphia, vol. 16, p. 233.

Lectotype: MNHN 4669 (1, 33), New Jersey, Delaware drainage, Brown's Mills; herein selected. D IX–10; A II, about 7; LL 17+31=48; cheeks, nape, breast scaly; interorbital naked. Fowler (1907), Hubbs and Cannon (1935), and Collette (1962) were unable to locate any types of this form at ANSP. Vaillant (1873, p. 134) wrote "L'exemplaire suivant envoyé à la collection du Muséum par cet auteur . . . ." with reference to its receipt from Cope in 1867. Figured in Vaillant, pl. 3, fig. 9.

=*Etheostoma* (*Hololepis*) *fusiforme fusiforme* (Girard). See Collette (1962).

Hololepis fusiformis atraquae Hubbs and Cannon, 1935, Misc. Publ. Mus. Zool. Univ. Michigan, no. 30, p. 68, pl. 1, fig. 11.

Holotype: UMMZ 107090 (♂, 31), Maryland, Prince Georges-Charles Co. line, Mattawoman Cr.; C. L. Hubbs, G. S. Myers, and E. D. Reid; May 21, 1933.

Paratypes: UMMZ 107089 (15, 27–32), USNM 117547 (2, 29–30), and USNM 92946 (4, 32–34), same data as holotype.

=*Etheostoma* (*Hololepis*) *fusiforme fusiforme* (Girard). See Collette (1962).

Hololepis fusiformis insulae Hubbs and Cannon, 1935, Misc. Publ. Mus. Zool. Univ. Michigan, no. 30, p. 83, pl. 1, fig. 15.

Holotype: MCZ 28274 (1, 24), Massachusetts, Nantucket Is., Gibbs Pond; H. Allen; "rec'd. Aug. 10, 1893."

Paratypes: UMMZ 86601 (2, 22–25) and MCZ 42078 (8, 16–26), same data as holotype. The latter was originally MCZ 33547, but because that number has also been used for a *Girardinus*, the paratypes have been recataloged.

=*Etheostoma* (*Hololepis*) *fusiforme fusiforme* (Girard). See Collette (1962).

Hololepis fusiformis metae-gadi Hubbs and Cannon, 1935, Misc. Publ. Mus. Zool. Univ. Michigan, no. 30, p. 81, pl. 1, fig. 14.

Holotype: USNM 77860 (♂, 32), Massachusetts, Barnstable Co., Osterville, Tempies Pond; V. Edwards; Nov. 12, 1902.

Paratypes: USNM 94683 (36, 27–43) and UMMZ 107093 (2, 31–38), same data as holotype.

=*Etheostoma* (*Hololepis*) *fusiforme fusiforme* (Girard). See Collette (1962).

Hololepis saludae Hubbs and Cannon, 1935, Misc. Publ. Mus. Zool. Univ. Michigan, no. 30, p. 50, pl. 1, fig. 6.

Holotype: UMMZ 107079 (1, 21), South Carolina, Saluda Co., Richland Cr., trib. of Lake Murray, 10 mi. SE. of Saluda; E. M. Burton; June 21, 1933.

Paratypes: UMMZ 107078 (2, 20–22), CM 33.149.1 (4, 16–22), and USNM 94685 (1, 21), same data as holotype. FMNH 38331 (1, 18), out of CM 33.149.1. UMMZ 107077 (4, 17–21) and CM 33.139.1 (4, 14–16), South Carolina, Saluda Co., Moore's Cr., trib. of Lake Murray, 6 mi. SE. of Saluda; Burton; June 21, 1933.

=*Etheostoma* (*Hololepis*) *saludae* (Hubbs and Cannon). See Collette (1962).

Hololepis serrifer Hubbs and Cannon, 1935, Misc. Publ. Mus. Zool. Univ. Michigan, no. 30, p. 31, pl. 1, fig. 2.

Holotype: UMMZ 107053 (♂, 53), North Carolina, Wake Co., Buffalo Cr. at Wendell; C. S. Brimley and Harris; Nov. 19, 1925.

Paratypes: The following are from North Carolina: USNM 93132 (♀, 45) and USNM 93133 (2♂, 43), Wilmington; W. P. Seal; March 1900. USNM 86163 (♀, 38), Wilmington; W. W. Welsh; Dec. 26, 1916. UMMZ 107056 (2, 33–36) and USNM 200333 (1, 34), Bertie

Co., Windsor; C. S. Brimley and W. B. Mabee; Oct. 21, 1924. UMMZ 107061 (1, 33), Martin Co., Williamston; Brimley; Oct. 23, 1924. UMMZ 107065 (♂, 40), Martin Co.; Jamesville; Brimley; Oct. 23, 1924. UMMZ 107054 (2, 34–38) and USNM 200335 (2, 38), Wake Co., Little R. at Wendell; Brimley and Mabee; Dec. 28, 1923. UMMZ 107064 (1, 33), same locality; Brimley and Harris; Nov. 19, 1925. UMMZ 94658 (2, 34–37), same locality; Brimley and Brady; Nov. 30, 1931. UMMZ 107060 (2, 37–43) and USNM 200330 (1, 38), Wake Co., Buffalo Cr. at Wendell; Brimley and Mabee; Nov. 30, 1923. UMMZ 107062 (♂, 37), same data; Mar. 30, 1925. UMMZ 107063 (5, 34–39) and USNM 200331 (5, 36–48), Johnston Co., Buffalo Cr., near Archer; Brimley and Mabee; Nov. 26, 1923. UMMZ 107066 (1, 37), Harnett Co., Black R. at Dunn; Brimley and Mabee; Nov. 19, 1923. UMMZ 107055 (3, 37–47) and USNM 200336 (4, 38–41), Johnston Co., Mingo Cr.; Brimley and Mabee; Nov. 19, 1923. UMMZ 107067 (3, 33–38) and USNM 200337 (3, 30–35), same data, Dec. 10, 1924. UMMZ 107059 (♂, 39) and USNM 200334 (2, 36–39), Harnett Co., Lillington; Brimley and Mabee; Dec. 11, 1923. UMMZ 107058 (1, 35), Harnett Co., Upper Little R. at Bunlevel; Brimley and Mabee; Dec. 11, 1923. UMMZ 107057 (1, 32) and USNM 200332 (1, 35), Sampson Co., Clinton; Brimley and Mabee; Nov. 20, 1923. UMMZ 70705 (1, 26), Moore Co., Lakeview; R. E. Coker; June 12, 1926. UMMZ 107073 (♀, 44), same data; Nov. 11, 1934. The following are from South Carolina: CM 34.215.1 (♂, 43), Marlboro Co., 6 mi. N. of Bennettsville; E. M. Burton; July 25, 1934. CM 33.260.1 (2, 32–34), Richland Co., Cedar Cr. on Leesville Rd.; Burton; Aug. 31, 1933. CM 33.264.1 (1, 32), Richland Co., old dam, near Wilson's Mill; Burton; Aug. 31, 1933. CM 34.179.1 (2, 33) and UMMZ 107075 (2, 32–33), Bamberg Co., Little Salkahatchie R., 3.5 mi. N. of Ehrhardt; Burton; July 11, 1934. CM 34.177.1 (2, 31–34) and UMMZ 107074 (2, 26–33), Colleton Co., Little Salkahatchie R., near Bell's Crossroads; Burton; July 11, 1934.

=*Etheostoma* (*Hololepis*) *serriferum* (Hubbs and Cannon). See Collette (1962).

Hololepis thermophilus Hubbs and Cannon, 1935, Misc. Publ. Mus. Zool. Univ. Michigan, no. 30, p. 63, pl. 1, fig. 10.

Holotype: UMMZ 107072 (♂, 32), North Carolina, Harnett Co., millpond at Kipling; C. S. Brimley and W. B. Mabee; Dec. 11, 1923.

Paratypes: UMMZ 107071 (2, 30) and USNM 200239 (2, 28–30), same data as holotype. UMMZ 107070 (♂, 31), North Carolina, Wake Co., Buffalo Cr. at Wendell; Brimley and Mabee; Nov. 26, 1923. UMMZ 107069 (1, 29), same data; Nov. 30, 1923. UMMZ

107068 (1, 29), North Carolina, Johnston Co., Big Swamp at Kenly; Brimley and Mabee; Nov. 26, 1923. USNM 52060 (8, 27–34) and USNM 52071 (6, 27–29), North Carolina, Wilmington; W. P. Seal. USNM 86165 (9, 26–30), North Carolina, ditch at Wilmington; W. W. Welsh; Dec. 29, 1916. USNM 86160 (2, 22–24), North Carolina, lake at Wilmington; "Grampus"; Jan. 3, 1917.

=*Etheostoma* (*Hololepis*) *fusiforme fusiforme* (Girard). See Bailey and Frey (1951) and Collette (1962).

Hololepis thermophilus oligoporus Bailey and Frey, 1951, Journ. Elisha Mitchell Sci. Soc., vol. 67, no. 2, p. 193, pl. 6, figs. 9–18; pl. 7, figs. 11–19; pl. 8, figs. 5–11.

Holotype: UMMZ 161969 (♂, 25), North Carolina, Bladen Co., Jones Lake; North Carolina lake survey; Sept. 10, 1947.

Paratypes: All from Bladen Co., N.C., collected by the North Carolina lake survey in 1947. Jones Lake: UMMZ 161968 (44, 15–27), same data as holotype. UMMZ 161970 (2, 21–23), June 17. UMMZ 161971 (3, 20–24), Aug. 26. UMMZ 161972 (38, 19–27), Aug. 28. DU uncat. (15, 21–25), Aug. 28. Salters Lake: UMMZ 161974 (46, 19–25), Sept. 9. UMMZ 161973 (2, 21), June 27. UMMZ 161975 (2, 18–20), July 4. Singletary Lake: UMMZ 161965 (2, 22–25), July 17. UMMZ 161966 (25, 17–27), Sept. 5. UMMZ 161967 (5, 22–25), Sept. 7.

=*Etheostoma* (*Hololepis*) *fusiforme fusiforme* (Girard). See Collette (1962).

Hololepis zonifer Hubbs and Cannon, 1935, Misc. Publ. Mus. Zool. Univ. Michigan, no. 30, p. 47, pl. 1, fig. 5.

Holotype: UMMZ 88803 (♀, 31), Alabama, Montgomery Co., pools of Catoma Cr., 5 mi. SW. of Montgomery; E. P. Creaser and H.R. Becker; Sept. 18, 1929.

Paratype: UMMZ 88822 (♀, 25), Alabama, Lowndes Co., Big Swamp Cr., 25 mi. SW. of Montgomery; Creaser and Becker; Sept. 18, 1929.

=*Etheostoma* (*Hololepis*) *zoniferum* (Hubbs and Cannon). See Collette (1962).

Hyostoma blennioperca Cope, 1868, Journ. Acad. Nat. Sci. Philadelphia, ser. 2, vol. 6, p. 215.

Lectotype: ANSP 14026 (♂, 85), Virginia; Holston R.; E. D. Cope; October 1867. Fowler (1907, p. 522) designated number 14026 as "type" but left it mixed with the other syntypes in the bottle. However, he mentioned that "the type as here restricted is evidently the largest in the collection." Therefore, the largest specimen is herein confirmed as lectotype by Dr. Robert V. Miller. D XIV–13;

A II, 8; LL 74; pectoral rays 15–15; cheeks and opercle, completely covered with scales; snout blunt, not overhung.

Paralectotypes: ANSP 14027–35 (8, 47–60), same data as lectotype. ANSP 14004 (1, 54), Virginia, Wythe Co., trib. of Kanawha R.; Cope; 1867. ANSP 14006–08 (3, 51–61), Virginia, Wythe Co., Walker's Cr., trib. of Kanawha R.; Cope; 1867. ANSP 14020–25 (6, 54–66), Virginia, Sinking Cr., trib. of Kanawha R.; Cope; 1867.

By selecting ANSP 14026 as lectotype, Fowler made the name *H. blennioperca* Cope applicable to the Holston River population of *E. blennioides*. *H. blennioperca* thereby becomes a synonym of *E. b. newmanii*, according to Miller (1964). However, the Kanawha River specimens represent the upper Ohio River subspecies *E. b. blennioides*, according to Miller (1964).

=*Etheostoma* (*Etheostoma*) *blennioides newmanii* (Agassiz). See Miller (1964).

Hyostoma Newmanii Agassiz, 1854, Amer. Journ. Sci. and Arts, vol. 17 p. 305.

Lectotype: USNM 1865 (♂, 93), Alabama, near Huntsville; Newman; herein selected by Dr. Robert V. Miller. D XIV–12; A II, 7; pectoral rays 15–15; LL 71; cheeks, opercles, and belly completely covered with scales.

Paralectotypes: MCZ 24602 (5, 68–106), orig. out of USNM 1865, then MCZ 237. UMMZ 86764 (1, 106), out of MCZ 24602.

=*Etheostoma* (*Etheostoma*) *blennioides newmanii* (Agassiz). See Miller (1964).

Hyostoma simoterum Cope, 1868, Journ. Acad. Nat. Sci. Philadelphia, ser. 2, vol. 6, p. 215, color pl. 24, fig. 5.

Syntypes: ANSP 14039–54 (16, 35–51), Virginia, Holston R.; E. D. Cope; October 1867. ANSP 14036–8 (3, 57–62); ANSP 14499–503 (5, 40–48); ANSP 5368–74 (7, 37–52); USNM 36604 (♂, 40); MNHN 4856 (1, 53), all with same data. Fowler (1907, p. 524) erroneously designated ANSP 14036 as lectotype and ANSP 14037–38 as paralectotypes of *Poecilichthys zonalis* Cope. These specimens are syntypes of *H. simoterum* as is clear from Fowler's figure 8 (see *P. zonalis*). With reference to the MNHN specimen, Vaillant (1873, p. 100) wrote "Cette espèce est représentée au Museum par un exemplaire type dû à l'obligeance de M. Cope."

=*Etheostoma* (*Ulocentra*) *simoterum* (Cope).

Ioa vigil Hay, 1882, Bull. U.S. Fish. Comm., vol. 2, p. 59.

Holotype: USNM 32201 (1, 23), Mississippi, Pearl R. at Jackson, O. P. Hay; July–August 1881.

=*Percina* sp. Perhaps *P.* (*Imostoma*) *uranidea* (Jordan and Gilbert). Not a species of *Ammocrypta* as has been presumed, but a species of *Percina* with a well-developed ctenoid caducous scale between the bases of the pelvic fins.

Microperca proeliaris Hay, 1881, Proc. U.S. Nat. Mus., vol. 3, p. 496.

Holotype: USNM 27418 (1, 26), Mississippi, Alcorn Co., trib. of Tuscumbia R. at Corinth; O. P. Hay; March–April 1880; in poor condition.

=*Etheostoma* (*Microperca*) *proeliare* (Hay).

Microperca punctulata Putnam, 1863, Bull. Mus. Comp. Zool., vol. 1, p. 4.

Syntypes: USNM 1377 (♂, 22; ♀, 24), Illinois, Calumet R., near Chicago; R. Kennicott. MCZ 24566 (2 ♀, 23–24); orig. out of USNM 1377, then MCZ 95. USNM 1283 (20, 23–30), Wisconsin, Oconomowac R., Lac la Belle; S. F. Baird; July 1853. MCZ 24570 (9, 24–31) and UMMZ 86457 (3, 24–31), orig. out of USNM 1283, then MCZ 93. USNM 1288 (28, 15–30), Michigan, Port Huron; Baird; August 1853. MCZ 24690 (11, 16–28) and UMMZ 86316 (3, 19–28), orig. out of USNM 1288, then MCZ 94; in poor condition. MCZ 24582 (1, 19), Michigan, Detroit R.; Baird; August, 1853; orig. USNM 1294, then MCZ 96; in poor condition. Also USNM 1276 (1, ?), Wisconsin, tribs. of Fox R., Vienna; Baird; August 1853; which we have been unable to locate.

=*Etheostoma* (*Microperca*) *microperca* Jordan and Gilbert because *punctulata* is preoccupied in *Etheostoma* by *Poecilichthys punctulatus* Agassiz.

Nanostoma elegans Hay, 1881, Proc. U.S. Nat. Mus., vol. 3, p. 493.

Lectotype: USNM 27445 (♂, 43), Mississippi, Clarke Co., shallow rocky branch of Chickasawha R. at Enterprise; O. P. Hay; March–April 1880; listed as type by Jordan and Evermann (1896, p. 1075); selection herein confirmed. D X–12; A II, 8; LL 42; branchiostegals 5–5; INF 7; POM 9; cheeks, opercles, and nape scaly; breast naked.

Paralectotype: SU 627 (1, 53), same data as lectotype.

=*Etheostoma* (*Etheostoma*) *zonale lynceum* (Hay) because *elegans* is preoccupied in *Etheostoma* by *Boleichthys elegans* Girard.

Nanostoma vinctipes Jordan, 1880, Proc. U.S. Nat. Mus., vol. 2, p. 236.

Lectotype: USNM 23454 (1, 47), Illinois, trib. of Illinois R. at Naperville; E. R. Copeland; listed as type by Jordan and Evermann (1896, p. 1075); selection herein confirmed. D XI–10; A II, 6; LL 46; branchiostegals 6–6; INF 7; POM 10; cheeks, opercles, breast, and nape scaly.

Paralectotypes: The whereabouts of the other four specimens from the type series is unknown.

=*Etheostoma* (*Etheostoma*) *zonale vinctipes* (Jordan), a valid subspecies according to Dr. Chu-fa Tsai (pers. comm.).

Nothonotus inscriptus Jordan and Brayton, 1878, U.S. Nat. Mus., Bull. 12(A), p. 34.

Lectotype: USNM 31145 (♀, 43), Georgia, Hall Co., Oconee R. at Sulphur Springs; D. S. Jordan and A. W. Brayton; summer, 1877; herein selected. D X–10; A II,8; LL 49; prevomerine teeth present; 6 dorsal blotches; cheeks, opercles, prepectoral area, and breast naked; nape completely scaled.

Paralectotype?: USNM 197439 (♂, 42), apparently same data as lectotype.

We select USNM 31145 as lectotype for the following reasons. The original description was based on two syntypes, male and female. USNM 31145 has the proper data and is labeled type, so it is clearly part of the type series. The male that we believe is the other syntype was discovered in the USNM collection labeled USNM 31132, *Etheostoma*, Etowah R., Georgia, Jordan and Brayton. *N. inscriptum* was reported only from the type locality in the original description, so it seems probable that this locality is in error. Under the species column in the USNM catalog we found the following entry for USNM 31132: "*Notropis stilbius Semotilus*, etc. (*Etheostoma*)," and for the locality "Etowah R., Rome, Ga. (chiefly)." It is apparent that the data for the specimen of *inscriptus* under USNM 31132 are totally confused. Therefore, in order to avoid further confusion should other specimens be found bearing this number, we recataloged this specimen as USNM 197439 and designate USNM 31145 as lectotype, because it is the specimen that we are certain is part of the type material.

=*Etheostoma* (*Etheostoma*) *inscriptum* (Jordan and Brayton).

Nothonotus thalassinus Jordan and Brayton, 1878, U.S. Nat. Mus. Bull. 12(A), p. 13.

Lectotype: USNM 31122 (♂, 40), South Carolina, Saluda R., near Greenville; D. S. Jordan and A. W. Brayton; summer, 1877; listed as type by Jordan and Evermann (1896, p. 1072); selection herein confirmed. D XII–12; A II,8; pectoral rays 15–14; LL 44; INF 8; POM 10; prevomerine teeth present; cheeks, opercles, prepectoral area, and breast naked; anterior portion of belly naked; nape scaled; 7 dorsal blotches.

Paralectotypes: SU 987 (♀, 46; 5 ♂, 37–49), South Carolina, Saluda R. at Farr's Mills, W. of Greenville; Jordan and Brayton; summer, 1877. MCZ 24397 (♂, 44), South Carolina, Saluda R. BMNH 1880.1.21.68 (♂, 52), South Carolina, Saluda R., Jordan.

=*Etheostoma* (*Etheostoma*) *thalassinum* (Jordan and Brayton).

Oligocephalus grahami Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 102.

Holotype: MCZ 24576 (1, 33), Texas, Devil's R.; J. H. Clark under Col. J. D. Graham; orig. USNM 1182, then MCZ 85.

=*Etheostoma* (*Oligocephalus*) *grahami* (Girard).

Oligocephalus humeralis Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 67.

Lectotype: USNM 1203 (♂, 42), Virginia, James R.; S. F. Baird; 1850; herein selected. D VII–13; A II,8: LL 36+11=47; INF 4+2; POM 10; supratemporal canal interrupted; cheeks, opercles, nape, and breast naked; about 11 vertical bars on body; tips of dorsal spines enlarged and slightly forked; branchiostegal membranes moderately joined.

Paralectotypes: USNM 198001 (45, 23–49), removed from USNM 1203. MCZ 24634 (10, 25–54), orig. out of USNM 1203, then MCZ 16. MCZ 35975 (2, 22–33), orig. out of USNM 1203.

=*Etheostoma* (*Catonotus*) *flabellare flabellare* Rafinesque.

Oligocephalus leonensis Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 102.

Syntypes: MCZ 24580 (2 ♀, 34–37), Texas, Río Leona; J. H. Clark; badly dried; orig. USNM 748, then MCZ 83.

=?*Etheostoma* (*Oligocephalus*) *lepidum* (Baird and Girard). Although most characters suggest *E. lepidum*, there are well-developed ctenoid scales on the opercle, a character of *E. grahami* which is found in tributaries of the Rio Grande. The body appears to be more elongate than in either *E. lepidum* or *E. grahami*.

Oligocephalus pulchellus Girard, 1859, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 102.

Holotype: MCZ 32950 (1, 28), Oklahoma, trib. of Gypsum Cr., trib. of Canadian R.; Lt. A. W. Whipple and party, exploration of railroad route near 35th parallel; orig. USNM 1334.

=*Etheostoma* (*Oligocephalus*) *spectabile pulchellum* (Girard). See Hubbs and Ortenburger (1929).

Perca minima Haldeman, 1842, Journ. Acad. Nat. Sci. Philadelphia, vol. 8, p. 330.

Holotype: ANSP 13928 (1, about 47), Pennsylvania, Susquehanna R.; S. S. Haldeman; a skin preserved in alcohol and reported to be in poor condition by Fowler (1907).

=*Etheostoma* (*Boleosoma*) *olmstedi olmstedi* Storer. See Storer (1846, p. 271).

Perca (*Percina*) *nebulosa* Haldeman, 1842, Journ. Acad. Nat. Sci. Philadelphia, vol. 8, p. 330.

Holotype: ANSP 22652 (♂, 110), Pennsylvania, Susquehanna R., S. S. Haldeman; figured by Fowler (1945, fig. 202).

=*Percina* (*Percina*) *caprodes semifasciata* (DeKay).

Percina bimaculata Haldeman, 1844, Proc. Boston Soc. Nat. Hist., vol. 1, p. 157.

Types: USNM 1405, "*Percina*, Susquehanna River, S. S. Haldeman, *Percina* dried.—orig. of Haldeman" may be the type of *P. bimaculata*, but we have been unable to find this specimen.

=*Percina* (*Percina*) *caprodes semifasciata* (DeKay).

Percina caprodes burtoni Fowler, 1945, Acad. Nat. Sci. Philadelphia Monogr., no. 7, p. 134, figs. 218–219.

Holotype: ANSP 70701 (1, 134), North Carolina, Buncombe Co., Swannanoa R., near Oteen; E. M. Burton; Aug. 21, 1934.

Paratype: ANSP 13707 (1, 66), Virginia, Holston R.; E. D. Cope.

=*Percina* (*Percina*) *caprodes burtoni* (Fowler).

Percina (*Hadropterus*) *lenticula* Richards and Knapp, 1964, Copeia, no. 4, p. 695, fig. 1 A–C.

Holotype: CU 43592 (♂, 96), Alabama, Bibb Co., Cahaba R. on Ala. 27, 8.5 mi. N. of Centerville; R. D. and J. S. Suttkus; May 9, 1959.

Paratypes: CU 43593 (♀, 95), Alabama, Bibb Co., Cahaba R. on Ala. 5, 2.2 mi. N. of Centerville; Suttkus and party; July 8, 1958. TU 15291 (7 ♀, 77–92) and CU 43594 (♂, 86), same locality as CU 43593; Suttkus, R. J. and H. V. Miller, and J. de Abate; Mar. 17, 1957. UG 209 (3 ♂, 1 ♀, 48–63), CU 43435 (1 ♂, 1 ♀, 55–58), USNM 197491 (♂, 64), and UMMZ 180074 (♂, 60), Georgia, Cherokee Co., Etowah R. at the mouth of Canton Town Cr.; C. M. Tarzwell; Oct. 8, 1950.

=*Percina* (*Hadropterus*) *lenticula* Richards and Knapp.

Percina manitou Jordan, 1877, Proc. Acad. Nat. Sci. Philadelphia, vol. 29, p. 53.

Lectotype: USNM 23458 (♀, 68), Indiana, Fulton Co., Lake Manitou; D. S. Jordan; labeled "drawn"; herein selected. D XV–14; A II,11; LL 86; breast and nape naked; cheeks and opercles scaled; one enlarged ctenoid scale on midline of anterior part of belly.

Paralectotypes: The original description was based on three specimens in the Indiana State collections. One of these possessed and the other two lacked "enlarged, mucronate plates." We have not been able to locate the other two syntypes (one male and one female) and therefore designate the syntype we have found as lectotype.

=*Percina* (*Percina*) *caprodes semifasciata* (DeKay).

Percina nigrofasciata raneyi Crawford, 1956, Tulane Stud. Zool., vol. 4, no. 1, p. 49, fig. 10.

Holotype: CU 23344 (♂, 79), South Carolina, Abbeville Co., Calhoun Cr., trib. of Savannah R., 7.6 mi. E. of Calhoun Falls on rt. 72; E. C. Raney, R. W. Crawford, R. H. Backus, C. R. Robins, J. N. Layne, and R. L. Wigley; Mar. 27, 1951.

Paratypes: CU 19599 (37, 43–78) and USNM 188896 (2♂, 75–78; 2♀, 61–63), same data as holotype.

=*Percina (Hadropterus) nigrofasciata raneyi* Crawford.

Percina (Alvordius) notogramma montuosa Hogarth and Woolcott, 1966, Chesapeake Sci., vol. 7, no. 2, p. 101, fig. 2.

Holotype: USNM 199556 (♂, 51), Virginia, Campbell Co., Beaver Cr. 4 mi. E. of Lynchburg on US 460; W. T. Hogarth and E. Collins; Oct. 20, 1964.

Paratypes (all from Virginia): UR 2337 (3, 40–57), Albemarle Co., Hog Cr., at jct. with Rockfish R. at jct. of Co. rt. 602 and 722; Hogarth, C. Beirne, L. Kiss; Apr. 15, 1965. UMMZ 144697 (3, 47–49), Rockbridge Co., North R.; L. C. Pettit; May 17, 1941. UMMZ 175103 (5, 52–62), Alleghany Co., Potts Cr. above jct. with Jackson R.; C. R. Gilbert and D. G. Myer; Sept. 13, 1957. UR 2294 (6, 34–59), Albemarle Co., jct. with Rock Castle Cr. and Totier Cr. 1.2 mi. S. Scottsville on Co. rt. 726; W. S. Woolcott and Hogarth; Apr. 1, 1965. VPI 1006 (2, 51–64), Craig Co., Craig Cr. 6.8 mi. from New Castle on rt. 311; R. D. Ross, Wakeman, Cook; Aug. 19, 1958. CU 47322 (1, 48), Craig Co., Craig Cr. 0.25 river mi. downstream from Pinetop; R. E. Jenkins, J. E. Carico, R. L. Miles; June 6, 1963. VPI 1014 (1, 68), Rockbridge Co., South R. 4.9 air mi. E. of Lexington; Ross, Wakeman, Cook, Carroll, Handley; Aug. 21, 1958. VPI 981 (1, 52), Bath Co., Jackson R. 1.5 mi. N. of Greenwood; Ross, Wakeman, Cook; July 15, 1958. CU 47321 (2, 56–63), Bath Co., Jackson R., Hidden Valley Farm 4.3 mi. N. Mitchell Town; Ross, Jenkins; July 20, 1963. VPI 954 (2, 64–67), Bath Co., Cow Pasture R., 0.4 mi. NE. Nimrod Hall; Ross, Wakeman, Cook; July 3, 1958. UR 2350 (1, 52), Nelson Co., Owens Cr. 2.3 mi. SE. Buffalo Springs on Co. rt. 626; Hogarth, Beirne, Kiss; Apr. 15, 1965. UR 1797 (3, 53–62), Craig Co., John's Cr., Co. rt. 632, 2 mi. NE. jct. Co. rt. 632 and 658; Woolcott and Ichthyology Class; June 27, 1963. UR 2321 (12, 33–58), Amherst Co., Partridge Cr., Co. rt. 622 at jct. Co. rt. 624 near Stapleton; Hogarth, Beirne, Kiss; Apr. 15, 1965. VPI 963 (1, 47), Bath Co., Jackson Cr. 8.5 mi. S. Bacova on Co. rt. 603; Ross, Wakeman, Cook; July 2, 1958. VPI 1005 (1, 55), Craig Co., Craig Cr., 3 mi. SE. New Castle; Ross, Wakeman, Cook; Aug. 19, 1958. USNM 199557 (3, 44–62), Campbell Co., Beaver Cr. 4 mi. E. Lynchburg on U.S. 460; Hogarth and E. J. Collins; Oct. 20, 1964. UMMZ 175121 (1, 51), Alleghany Co., Potts Cr.; Gilbert and Myer; Sept. 13,

1957. UMMZ 95194 (1, 41), Alleghany Co., Dunlap Cr.; C. L. and L. C. Hubbs; Sept. 10, 1928.

=*Percina* (*Alvordius*) *notogramma montuosa* Hogarth and Woolcott.

Pileoma carbonaria Baird and Girard, 1853, Proc. Acad. Nat. Sci. Philadelphia, vol. 6, p. 387.

Lectotype: USNM 740 (♂, 85), Texas, Río Salado, 4 mi. from San Antonio; J. H. Clark; herein selected. D XV–15; A II, 11; LL 90; breast naked; cheeks, opercles, and nape completely covered with scales.

Paralectotypes: USNM 197999 (2 ♂, 75–87; ♀, 73), removed from USNM 740. MCZ 24599 (2 ♂, 88–108) and UMMZ 86594 (♂, 86), orig. out of USNM 740, then MCZ 269.

Jordan and Evermann (1896, p. 1027) also listed USNM 742 as "type." This specimen was taken by Kennerly in San Pedro Creek; there is no mention of either this locality or collector in the original description, so the specimen is not part of the type series.

= *Percina* (*Percina*) *caprodes carbonaria* (Baird and Girard).

Pileoma cymatogramma Abbott, 1860, Proc. Acad. Nat. Sci. Philadelphia, vol. 12, p. 327.

Holotype: ANSP 14009 (♀, 45), no locality.

= *Etheostoma* (*Etheostoma*) *blennioides blennioides* Rafinesque. See Miller (1964).

Pileoma semifasciatum DeKay, 1842, Nat. Hist. New York Zool., vol. 1, pt. 4, p. 16, pl. 50, fig. 162.

Syntypes: ?New York, Westport on Lake Champlain; J. E. DeKay; figure based on material then in the N.Y. State collection. Dr. E. M. Reilly, Curator of Zoology, has informed us that the types of this species are no longer present in the New York State Museum.

Topotypes are available: MCZ 24613 (5, 41–77), S. F. Baird.

= *Percina* (*Percina*) *caprodes semifasciata* (DeKay).

Pileoma zebra Agassiz, 1850, Lake Superior, p. 308, pl. 4, fig. 4.

Syntypes: MCZ 24636 (♂, 51; ♀, 60), Ontario, Lake Superior, "The Pic" at the mouth of the Pic R.; L. Agassiz; about July 13, 1848; orig. USNM 1175, then MCZ 257. UMMZ 86592 (1, 53) out of MCZ 24636.

= *Percina* (*Percina*) *caprodes semifasciata* (DeKay). See Hubbs and Brown (1929, p. 47).

Plesioperca anceps Vaillant, 1873, Nouv. Arch. Mus. Hist. Nat. Paris, vol. 9, p. 37, pl. 1, fig. 3.

Holotype: MNHN 2778 (♂, 86), locality unknown; donated by Agassiz; orig. MCZ 851.

= *Percina* (*Hadropterus*) *nigrofasciata nigrofasciata* (Agassiz).

See Jordan (1880, p. 225) and Crawford (1956).

Pleurolepis asprellus Jordan, 1878, Bull. Illinois State Lab. Nat. Hist., vol. 1, no. 2, p. 38.

Holotype: INHS uncat. (1, 90), Illinois, Hancock Co., small rocky trib. of Mississippi R.; C. K. Worthen.

Paratypes: ?(1, ?), same data as holotype. ? Illinois, Effingham Co., Little Wabash R.; S. A. Forbes; July 1877. We have been unable to find any paratypes of this species. The types were originally in the collection of the Illinois State Laboratory of Natural History. Smith and Bridges (1960, p. 254) did not list any type material of this species in the collections of the Illinois Natural History Survey which is the State Laboratory's successor, but Dr. Smith recently found the holotype for us.

= *Ammocrypta* (*Crystallaria*) *asprella* (Jordan).

Pleurolepis pellucidus Agassiz *in* Putnam, 1863, Bull. Mus. Comp. Zool., vol. 1, p. 5.

Lectotype: USNM 1311 (1, 50), Ohio, Black R., below falls at Elyria; S. F. Baird; August 1853; orig. no. 17. USNM 1311, then containing 21 specimens, was listed as type by Jordan and Evermann (1896, p. 1063); Linder (1959, p. 182) selected 1 specimen as lectotype.

Paralectotypes: USNM 164165 (20, 40–48) removed from USNM 1311 by Linder (1959). MCZ 24616 (9, 30–47) and UMMZ 86489 (3, 47–50) orig. out of USNM 1311, then MCZ 270. Although not mentioned by Jordan and Evermann or Linder, these collections are obviously part of the original material and come from the type locality and so must be considered parlectotypes.

There is no mention of any localities in the original description of *P. pellucidus*, but the following specimens were probably part of the original material. USNM 1289 (1, 49), Michigan, Port Huron; Baird; August 1853. USNM 1295 (1, 39), Mich., Detroit R.; Baird; August 1853. MCZ 24626 (4, 44–49) and UMMZ 86479 (1, 46), Ohio, Rockport; Kirtland.

=*Ammocrypta* (*Ammocrypta*) *pellucida* (Agassiz) not *A. pellucida* (Baird) as frequently given because the Baird name was listed as a synonym in Putnam and therefore has no status.

Poecilichthys artesiae Hay, 1881, Proc. U.S. Nat. Mus., vol. 3, p. 494.

Holotype: USNM 27434 (♂, 63), Mississippi, Lowndes Co., Catawba Cr., trib. of Tombigbee R. at Artesia; O. P. Hay; March–April 1880.

=*Etheostoma* (*Oligocephalus*) *whipplii artesiae* (Hay). See Hubbs and Black (1941).

Poecilichthys asprigenis Forbes *in* Jordan, 1878, Bull. Illinois State Lab. Nat. Hist., vol. 1 no. 2, p. 41.

Syntypes: SU 2201 (2, 38–39), Illinois, small creek near Pekin. The original description was based on 14 specimens from the type locality, but we have been unable to locate the other 12. Smith and Bridges (1960) did not report any type specimens of this species in the collections of the Illinois Natural History Survey which inherited the material of the Illinois State Laboratory.

MCZ 25051 (1, 45), Illinois, Peoria, 1880, is labeled as cotype but was collected after the original description was published and came from Peoria rather than from Pekin.

=*Etheostoma* (*Oligocephalus*) *asprigene* (Forbes).

Poecilichthys beani Jordan, 1884, Proc. U.S. Nat. Mus., vol. 7, p. 479.

Holotype: USNM 35754 (♀, 36), Missouri, Lafayette Co., Tabo Cr., trib. of Missouri R., near Lexington.

=*Etheostoma* (*Boleosoma*) *nigrum nigrum* Rafinesque. Jordan (1885, p. 548) admitted *P. beani* was a mutilated individual of *Boleosoma maculatum* (=*E. nigrum*).

Poecilichthys borealis Jordan, 1884, Proc. U.S. Nat. Mus., vol. 7, p. 477.

Lectotype: USNM 35747 (♂, 41), Canada, Montreal; T. J. Doran; herein selected. D IX–11; A II,7; LL 20+34=54; INF 8; POM 10; supratemporal canal widely interrupted; cheeks, opercles, nape, and belly covered with scales; few scattered scales on breast and prepectoral region.

Paralectotypes: USNM 197993 (3, 35–48), removed from USNM 35747. The fifth syntype mentioned in the original description is in SU 5447 but unfortunately became mixed with two specimens from Gravenhurst, Canada (SU 6261) during the earthquake.

=*Etheostoma* (*Oligocephalus*) *exile* (Girard). See Hubbs (1926, p. 67) and Richardson (1938).

Poecilichthys butlerianus Hay, 1883, Bull. U.S. Fish Comm., vol. 2, p. 61.

Holotype: USNM 32224 (1, 43), Mississippi, Yazoo Co., Big Black R., near Vaughn's Station; O. P. Hay; Aug. 20, 1881.

=*Etheostoma* (*Hololepis*) *gracile* (Girard). See Hubbs and Cannon (1935) and Collette (1962).

Poecilichthys camurus Cope, 1870, Proc. Amer. Philos. Soc., vol. 11, p. 265.

Lectotype: ANSP 13741 (1, 55), Tennesee, headwaters of Cumberland R.; herein selected by Dr. Edward C. Raney. D X–13; A II,9; LL 58.

Paralectotypes: ANSP 13742–44 (3, 49–56), same data as lectotype.

The types were found mixed in with the types of *Poecilichthys sanguifluus* Cope by Dr. Edward C. Raney.

=*Etheostoma* (*Nothonotus*) *camurum* (Cope). See Bailey (1959).

Poecilichthys coosae Fowler, 1945, Acad. Nat. Sci. Philadelphia, Monogr., no. 7, p. 356, figs. 226–228.

Holotype: ANSP 71189 (1, 38), Alabama, Cherokee Co., small cr., ¼ mi. NE. of Chesterfield, Coosa R. drainage; G. A. Coventry and C. B. Peterson; July 7, 1942.

Paratypes: All collected by Coventry and Peterson in Cherokee Co., Ala. ANSP 71190–91 (2, 34–35), same data as holotype. ANSP 71192–95 (4, 32–50), Cowan's Cr., Jordan's store; July 3, 1942. ANSP 71196 (♀, 39), cave on Lookout Mt., "Split Rock" at Little R. Gulch; July 1, 1942.

=*Etheostoma (Ulocentra) coosae* (Fowler).

Poecilichthys euzonus erizonus Hubbs and Black, 1940, Occ. Pap. Mus. Zool. Univ. Michigan, no. 416, p. 17, pl. 1, fig. 2.

Holotype: UMMZ 124597 (♂, 66), Missouri, Ripley Co., Current R. at "The Nook," T. 23 N., R. 2 E., sec. 9; A. H. Denney; Aug. 10, 1938.

Paratypes: UMMZ 124598 (5, 44–57), same data as holotype. UMMZ 124595 (8, 60–70), Missouri, Carter Co., Carter County Hunting and Fishing Club, T. 26 N., R. 1 E., sec. 11 and 12; Denney; July 25, 1938. UMMZ 124596 (2, 36–62), Missouri, Ripley Co., Doniphan Boat Landing, T. 23 N., R. 2 E., sec. 27; Denney; July 26, 1938. UMMZ 124599 (2, 58), Missouri, Carter Co., Current R., just above mouth of Pike Cr., T. 27 N., R. 1 W., sec. 23; Denney; Aug. 18, 1938.

=*Etheostoma* (*Etheostoma*) *euzonum erizonum* (Hubbs and Black.)

Poecilichthys euzonus euzonus Hubbs and Black, 1940, Occ. Pap. Mus. Zool. Univ. Michigan, no. 416, p. 23, pl. 1, fig. 3.

Holotype: UMMZ 123548 (♂, 61), Arkansas, Searcy Co., Buffalo R., 4 mi. SE. of St. Joe; J. D. and R. Y. Black; July 8, 1938.

Paratypes: UMMZ 124594 (4, 28–51), and USNM 117587 (1, 35), same data as holotype. UMMZ 123391 (2, 42–43), Arkansas, Madison Co., King's R., 3 mi. E. of Alabam at Denney Cave; J. D. and R. Y. Black; June 30, 1938. UMMZ 123504 (1, 45), Arkansas, Carroll Co., White R. near Busch; J. D. and R. Y. Black; July 8, 1938.

=*Etheostoma* (*Etheostoma*) *euzonum euzonum* (Hubbs and Black).

Poecilichthys gutselli Hildebrand, 1932, Journ. Elisha Mitchell Sci. Soc., vol. 48, no. 1, p. 78, pl. 3.

Holotype: USNM 92402 (♂, 71), North Carolina, Swain Co., Tuckaseegee R. at Ela; J. S. Gutsell; Aug. 26, 1930.

Paratypes: USNM 197411 (♀, 75), same data as holotype. USNM 92580 (♀, 37), North Carolina, Jackson Co., Tuckaseegee R., below Cullowhee; Gutsell; Aug. 29, 1930.

=*Etheostoma* (*Etheostoma*) *blennioides gutselli* (Hildebrand). See Miller (1964).

Poecilichthys hopkinsi Fowler, 1945, Acad. Nat. Sci. Philadelphia Monogr., no. 7, p. 249, fig. 206.

Holotype: ANSP 71548 (♀, 44), Georgia, Wilcox Co., Osewitchee Springs, 14 mi. N. of Fitzgerald; M. N. Hopkins, Jr.; Aug. 15, 1942.

Paratypes: ANSP 71567–69 (3, 25–45), same locality and collector as holotype; June 29, 1944.

=*Etheostoma* (*Oligocephalus*) *hopkinsi hopkinsi* (Fowler). See Bailey and Richards (1963).

Poecilichthys jessiae Jordan and Brayton *in* Jordan, 1878, Manual Vertebrates, 2nd ed., p. 227, and *in* Jordan and Brayton, 1878, U.S. Nat. Mus. Bull. 12(A), p. 59.

Syntypes: ? "sev. spec. each about 2″ long," Georgia, Chickamauga R. at Ringgold; D. S. Jordan and A. W. Brayton; summer, 1877. We have been unable to find any of the type material of this species. Figure 4 was found in the files of the Division of Fishes labeled as "*Poecilichthys jessiae,* Chickamauga River, Ga." We feel that it is probably based on one of the types and so reproduce it here.

=*Etheostoma* (*Boleosoma*) *jessiae* (Jordan and Brayton).

Poecilichthys kanawhae Raney, 1941, Occ. Pap. Mus. Zool. Univ. Michigan, no. 434, pl. 1.

Holotype: UMMZ 131837 (♂, 72), North Carolina, Ashe Co., N. Fork of New R. on rt. 16 at Crumpler; E. C. Raney, E. A. Lachner, and L. J. Kezer; Apr. 1, 1940.

Paratypes: UMMZ 131838 (7, 39–60) and CU 7663 (13, 39–57), same data as holotype. CU 7678 (2♂, 48–53), North Carolina, Ashe Co., N. Fork of New R., 1 mi. NNE. of Warrensville; Raney, Lachner, Kezer; Apr. 1, 1940. CU 7830 (3, 42–69) and UMMZ 131834 (2, 35), North Carolina, Ashe Co., N. Fork of New R., 1 mi. NNE. of Creston; Raney, Lachner, Kezer; Apr. 2, 1940. CU 7688 (5, 44–59) and UMMZ 131836 (2, 50–56), North Carolina, Ashe Co., S. Fork of New R. on rt. 16 at Index; Raney, Lachner, Kezer; Apr. 2, 1940. CU 7693 (3, 40–44) and UMMZ 131835 (2, 40–42), North Carolina, Ashe Co., S. Fork of New R., 1 mi. SW. of Fleetwood; Raney, Lachner, Kezer; Apr. 2, 1940. UMMZ 95371 (2, 30–44), Virginia, Carroll Co., Big Reed Island Cr.; C. L. Hubbs and E. P. Creaser; May 17, 1931. USNM 107679 (3, 46–59), Virginia, Carroll

Co., Crooked Cr., 4 mi. E. of Galax; L. P. Schultz and E. D. Reid; July 13, 1938.

=*Etheostoma* (*Etheostoma*) *kanawhae* (Raney).

Poecilichthys mesaeus Cope, 1864, Proc. Acad. Nat. Sci. Philadelphia, vol. 16, p. 232.

Lectotype: ANSP 13943 (♀, 49), Nebraska, Platte R., near Ft. Kearney; W. Hammond; selected and illustrated by Fowler (1907, p. 524, fig. 7).

Paralectotypes: ANSP 13944–46 (3), same data as lectotype. Fowler wrote "Type, No. 13,943, A.N.S.P." and did not mention these three specimens.

=*Etheostoma* (*Boleosoma*) *nigrum nigrum* Rafinesque.

Poecilichthys osburni Hubbs and Trautman, 1932, Ohio Journ. Sci., vol. 32, no. 1, p. 34, fig. 2.

Holotype: UMMZ 92409 (♂, 75), West Virginia, Pocohontas Co., Stony Cr., trib. of Greenbrier R.; J. Addair; June 2, 1931.

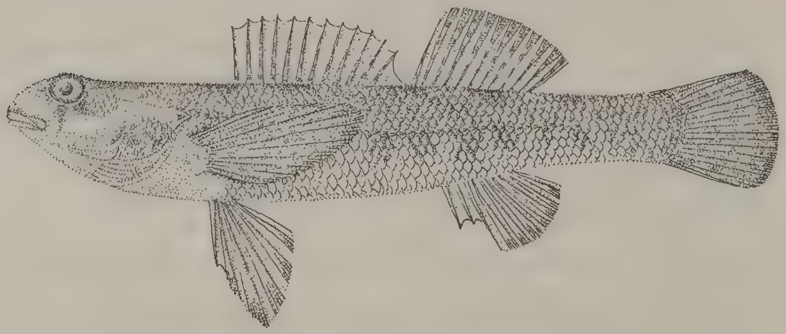

FIGURE 4.—*Poecilichthys jessiae* Jordan and Brayton, Chickamauga River, Ga. (previously unpublished drawing by Ernest Copeland that probably represents one of the lost syntypes).

Paratypes: UMMZ 92410 (5, 58–85), and OSM 12946 (4, 56–81), same data as holotype. USNM 39542 (♀, 56), Virginia, South Fork Reed's Cr.; M. McDonald. UMMZ 95370 (7, 49–57), and USNM 117588 (♀, 64), Virginia, Wythe Co., Reed Cr., trib. of New R., 2–3 mi. below Max Meadows; C. L. Hubbs and E. P. Creaser; May 17, 1931.

=*Etheostoma* (*Etheostoma*) *osburni* (Hubbs and Trautman). See Raney (1941).

Poecilichthys palustris Gilbert, 1884, Proc. U.S. Nat. Mus., vol. 7, p. 209.

Lectotype: USNM 34983 (♂, 30), Indiana, Greene Co., Switz City Swamp; C. H. Gilbert; August 1883; selected by Hubbs and Cannon (1935, p. 44).

Paralectotype: Gilbert mentioned a second specimen in his original description which has apparently been lost (Hubbs and Cannon, 1935, p. 44).

=*Etheostoma* (*Hololepis*) *gracile* (Girard). See Hubbs and Cannon (1935) and Collette (1962).

Poecilichthys punctulatus Agassiz, 1854, Amer. Journ. Sci. and Arts, vol. 17, p. 304.

Lectotype: MCZ 39 (1, 52), Missouri, Osage R.; G. Stolley; herein selected. D XII–14; A II, 8; LL 59+13=72; INF 8; POM 10; supratemporal canal widely incomplete; cheeks and opercles naked; color pattern completely faded.

Paralectotype: MCZ 43091 (1, 48), removed from MCZ 39.

=*Etheostoma* (*Oligocephalus*) *punctulatum* (Agassiz).

Poecilichthys quiescens Jordan, 1884, Proc. U.S. Nat. Mus., vol. 7, p. 478.

Holotype: USNM 28509 (♂, 36), Georgia, trib. of Altamaha R. [error for Alapaha R.], a branch of the Suwanee R. at Nashville; W. J. Taylor.

=*Etheostoma* (*Hololepis*) *fusiforme barratti* (Holbrook). See Hubbs and Cannon (1935) and Collette (1962).

Poecilichthys radiosus cyanorum Moore and Rigney, 1952, Copeia, no. 1, p. 10, pl. 1, figs. 3–4.

Holotype: UMMZ 161366 (♂, 68), Oklahoma, Johnston Co., Blue R., trib. of Red R., on U.S. 99, T. 1 S., R. 6 E.; G. A. Moore; Apr. 4, 1949; orig. OAM 2914.

Paratypes: All from the Blue R., Oklahoma, collected by G. A. Moore and students. OAM 2913 (96, 27–67), same data as holotype. UMMZ 161367 (77, 32–70), same locality; Apr. 5, 1947. MCZ 37204 (11, 33–53), Blue R., 10 mi. W. of Wapanucka, 3 mi. S. of rt. 7; Apr. 6, 1947; orig. OAM 1497. UOMZ 26154 (82, 28–53), Little Blue R., T. 1 N., R. 6 E., NW. sec. 36; Apr. 5, 1947. UOMZ 26155 (15, 39–49), Bryan Co., Cedar Cr., 7 mi. E. and 1 mi. S. of Durant; Apr. 15, 1949. USNM 153532 (49, 38–54), Pontotoc Co., Blue R., near source, SW. of Ada; orig. OAM 1587.

=*Etheostoma* (*Oligocephalus*) *radiosum cyanorum* (Moore and Rigney).

Poecilichthys radiosus paludosus Moore and Rigney, 1952, Copeia, no. 1, p. 11, pl. 2, figs. 3–4.

Holotype: UMMZ 161368 (♂, 47), Oklahoma, Pontotoc Co., Bois d'Arc Cr., trib. of Clear Boggy Cr., T. 2 N., R. 6 E.; E. Leonard, J. Stevenson, M. Chapman; Apr. 16, 1949; orig. OAM 2933.

Paratypes: All from Oklahoma. UMMZ 161369 (58, 30–45), same data as holotype. MCZ 37205 (41, 36–60), Pontotoc Co., Clear Boggy Cr.; Moore; Apr. 16, 1947; orig. OAM 1625. UOMZ 26156 (19, 28–39), Pontotoc Co., Jack Fork, Clear Boggy system, T. 2 N., R. 6 E.; J. M. McDowell, P. White, R. Loomis; Apr. 16, 1949. OAM 1703 (2, 36–41), Kiamichi R., S. of Talahina; Moore et al.; June 7, 1947. USNM 153533 (38, 27–39), Pushmataha Co., small trib., T. 2 N., R. 21 E., sec. 17; A. P. Blair and J. T. Herbelin; Apr. 16, 1949. UOMZ 26157 (36, 26–35), Latimer Co., Buffalo Cr., 21 mi. S. of Wilburton, T. 3 N., R. 19 E.; Blair and Herbelin; Apr. 17, 1949. USNM 198109 (27, 30–39), Pushmataha Co., Kiamichi R., SE. of Clayton, T. 1 N., R. 19 E., sec. 7; Blair and Herbelin; Apr. 16, 1949; orig. TUC uncat.

=*Etheostoma* (*Oligocephalus*) *radiosum paludosum* (Moore and Rigney).

Poecilichthys rufilineatus Cope, 1870, Proc. Amer. Philos. Soc., vol. 11, p. 267.

Lectotype: ANSP 13791 (1) North Carolina, Madison Co., Warm Springs Cr., trib. of French Broad R.; E. D. Cope. Selected and illustrated by Fowler (1907, p. 525, fig. 9). Still mixed with paralectotypes, a total of seven specimens (42–58).

Paralectotypes: ANSP 13792–97 (6), same data as holotype.

=*Etheostoma* (*Nothonotus*) *rufilineatum* (Cope). See Bailey (1959).

Poecilichthys sagitta Jordan and Swain, 1883, Proc. U.S. Nat. Mus. vol. 6, p. 250.

Holotype: ? (1, 2½ in. TL), Kentucky, Whitley Co., Wolf Cr., trib. of Clear Fork of Cumberland R., near Pleasant View; D. S. Jordan, J. Swain, et al.; May 1883. According to the original description, the type should be in the USNM collection, but we have been unable to find it here or elsewhere.

=*Etheostoma* (*Oligocephalus*) *sagitta sagitta* (Jordan and Swain). See Bailey (1948) and Kuehne and Bailey (1961).

Poecilichthys sanguifluus Cope, 1870, Proc. Amer. Philos. Soc., vol. 11, p. 264.

Lectotype: ANSP 13738 (1, 55), Tennessee, headwaters of South Fork of Cumberland R.; E. D. Cope; herein selected by Dr. Edward C. Raney.

Paralectotypes: ANSP 13739–40 (2, 48–50), same data as lectotype. Fowler (1907, p. 524) referred to seven syntypes of *P. sanguifluus*, ANSP 13738 (type) to 13744. Three are types of *Poecilichthys camurus* Cope (q.v.).

=*Etheostoma* (*Nothonotus*) *maculatum sanguifluum* (Cope) according to Raney and Zorach (MS).

Poecilichthys saxatilis Hay, 1881, Proc. U.S. Nat. Mus. vol. 3, p. 495.

Holotype: USNM 27433 (1, 31), Mississippi, Clarke Co., trib. of Chickasawha R. at Enterprise; O. P. Hay; March-April 1880.

=*Etheostoma* (*Boleosoma*) *stigmaeum* (Jordan). See Bailey, Winn, and Smith (1954, p. 142).

Poecilichthys spectabilis Agassiz, 1854, Amer. Journ. Sci. and Arts, vol. 17, p. 304.

Lectotype: UMMZ 86340 (♂, 48), Missouri, Osage R., G. Stolley; out of MCZ 24503+24529+24722; herein selected by Mr. Donald A. Distler. D XI–13; A II, 6; LL 27+19=46; INF 4+3; pectoral rays 11; supratemporal canal complete.

Paralectotypes: UMMZ 179528 (6, 27–35), same data as lectotype; 1 specimen of *E. caeruleum* removed by Distler and recataloged as UMMZ 179529. MCZ 24503+24529+24722 (21, 27–40); 15 of the specimens in poor condition from drying; 3 specimens of *E. caeruleum* removed and recataloged as MCZ 42077. USNM 120284 (5, 32–48), out of MCZ 24503, 1 specimen of *E. caeruleum* removed and recataloged as USNM 196738.

=*Etheostoma* (*Oligocephalus*) *spectabile spectabile* (Agassiz). See Trautman (1930).

Poecilichthys swaini Jordan, 1884, Proc. U.S. Nat. Mus., vol. 7, p. 479.

Holotype: USNM 35308 (♂, 41), Mississippi, Lawrence Co., trib. of Pearl R. at Monticello.

=*Etheostoma* (*Oligocephalus*) *swaini* (Jordan).

Poecilichthys tetrazonus Hubbs and Black, 1940, Occ. Pap. Mus. Zool. Univ. Michigan, no. 416, p. 11, pl. 1, fig. 1.

Holotype: UMMZ 111330 (1, 33), Missouri, Dallas Co., Big Niangua R. at mouth of Greasy Cr., 6 mi. SE. of Buffalo; J. C. Salyer; Aug. 28, 1931.

Paratype: UMMZ 124600 (1, 22), same data as holotype.

=*Etheostoma* (*Etheostoma*) *tetrazonum* (Hubbs and Black).

Poecilichthys versicolor Agassiz, 1854, Amer. Journ. Sci. and Arts, vol. 17, p. 304.

Lectotype: USNM 1822 (♂, 42), Illinois, small creeks near Quincy; L. Watson; herein selected. D IX–14; A II, 7; LL 28+19=47; INF 4+3; POM 10; supratemporal canal complete.

Paralectotypes: USNM 197493 (5, 34–40), removed from USNM 1822; 1 specimen that is apparently an aberrant *spectabile* recataloged as USNM 197443.

USNM 1816, Missouri, Osage R.; G. Stolley is listed in the USNM catalog as type material, but these specimens have apparently been mixed with the paralectotypes of *Poecilichthys spectabilis* Agassiz in MCZ 24722.

=*Etheostoma* (*Oligocephalus*) *spectabile spectabile* (Agassiz).

Poecilichthys virgatus Jordan, 1880, Proc. U.S. Nat. Mus., vol. 2, p. 236.

Lectotype: USNM 23456 (1, 39), Kentucky, Rock Castle R. at Livingston; D. S. Jordan; selected by Jordan and Evermann (1896, p. 1093).

Paralectotypes: Of the "numerous typical examples" mentioned in the original description, we have been able to locate only one specimen other than the holotype. UMMZ 187511 (1, 41), same data, orig. IU 451, then IU 4748. A specimen was supposed to have been sent to the British Museum, but Collette could find no record of this having been done and could not find such a specimen in their collection in October 1963.

=*Etheostoma* (*Catonotus*) *virgatum* (Jordan).

Poecilichthys vitreus Cope, 1870, Proc. Amer. Philos. Soc., vol. 11, p. 263.

Holotype: ?, North Carolina, Wake Co., Walnut Cr., trib. of Neuse R.; E. D. Cope; late November. Types of other species described by Cope in the 1870 paper were deposited at ANSP, but Fowler (1907) did not mention the type (a female) of this species, and we have been unable to find it in several thorough searches.

=*Etheostoma* (*Ioa*) *vitreum* (Cope).

Poecilichthys vulneratus Cope, 1870, Proc. Amer. Philos. Soc., vol. 11, p. 266.

Holotype: ANSP 13798 (♂, 44), North Carolina, Madison Co., Warm Springs Cr., trib. of French Broad R. Found in bottle containing the types of *Poecilichthys rufilineatus* Cope by Dr. Edward C. Raney.

=*Etheostoma* (*Nothonotus*) *maculatum vulneratum* (Cope), according to Raney and Zorach (MS).

Poecilichthys whipplii montanus Hubbs and Black, 1941, Occ. Pap. Mus. Zool. Univ. Michigan, no. 429, p. 15, pl. 1, fig. 2.

Holotype: UMMZ 127777 (♂, 75), Arkansas, Washington Co., near head of Blue Hole Cr., trib. of Clear Cr., 1 mi. S. of Winslow; J. D. Black and J. Yerton; June 17, 1939.

Paratypes: USMM 117589 (7, 17–56), same locality as holotype; J. D. and R. Y. Black; Aug. 3, 1938; orig. UMMZ 123802. The remainder of the paratypes are all UMMZ specimens from Arkansas. 128678 (2, 24–48), Crawford Co., Schaberg Cr., trib. of Frog Bayou; Black, Mills, and Yerton; Aug. 17, 1939. 123806 (100, 16–72), Washington Co., Blue Hole Cr., Blue Hole, T. 13 N., R. 30 W.; Black and Yerton; Aug. 3, 1938. 123813 (107, 17–54), Washington Co., Railroad Cr., trib. of Frog Bayou, 1.5 mi. S. of Winslow; Black and Yerton; Aug. 4, 1938. 123821 (53, 17–64), Washington Co., Railroad Cr., below Cliff Hole, trib. of Frog Bayou, T. 13 N., R. 30 W.; Black and Yerton; Aug. 4, 1938. 123352 (1, 33), Crawford Co., Jones Cr., 1 mi. W. of Wintrey, T. 12 N., R. 29 W.; Black and Yerton; June 29, 1938. 123842 (2, 41), Crawford Co., Schaberg Cr., trib. of Frog Bayou, near Schaberg, T. 12 N., R. 30 W.; Black and party; Aug. 5, 1938. 127778 (7, 27–63), Washington Co., Blue Hole Cr., 1 mi. S. of Winslow; Black and Yerton; June 17, 1939. 123802 (220, 14–69), Washington Co., Blue Hole Cr., 1.5 mi. S. of Winslow, T. 13 N., R. 30 W.; Black and Yerton; Aug. 3, 1938.

=*Etheostoma* (*Oligocephalus*) *whipplii montanum* (Hubbs and Black).

Poecilichthys whipplii radiosus Hubbs and Black, 1941, Occ. Pap. Mus. Zool. Univ. Michigan, no. 429, p. 10, pl. 1, fig. 1.

Holotype: UMMZ 123080 (♂, 50), Arkansas, Hot Spring Co., Sugar Loaf Cr., trib. of Caddo R., Ouachita R. system; J. D. and R. Y. Black; June 19, 1938.

Paratypes: USNM 36419 (5, 22–30), Arkansas, Ouachita R. at Arkadelphia; D. S. Jordan and C. H. Gilbert. USNM 36442 (19, 22–46), Arkansas, Saline R. at Benton; Jordan and Gilbert. USNM 42766 (1, 27), Arkansas, Hot Springs; Meek.

The following paratypes are all UMMZ specimens from Oklahoma: 73056 (1, 45), Kiamichi R., 4 mi. E. of Tuskahoma. 81136 (1, 42), Le Flore Co., 8 mi. W. of Arkansas line; June 18, 1927. 109033 (2, 21–25), Pushmataha Co., Ten Mile Cr., trib. of Kiamichi R., 4 mi. NW. of Miller; June 26, 1929. 109036 (1, 47), Atoka Co., Little Boggy Cr., 5 mi. NE. of Atoka; June 28, 1928. 109448 (2, 45), Pushmataha Co., Walnut Cr., trib. of Kiamichi R., 1 mi. SW. of Albion; June 19, 1931. 110863 (3, 33–46), Le Flore Co., trib. of Big Cedar Cr., near NW. end of Rich Mt.; June 26, 1934. 129696 (1, 34), McCurtain Co., Glover R., one-fourth mi. W. of Glover; W. F. and P. F. Blair; June 16, 1938. 105393 (1, 27), Big Hell Cr., trib. of Ouachita R. at Mimoca, 7 mi. N. of Norman; Holloway; Mar. 25, 1937.

The following paratypes are all UMMZ specimens from Arkansas: 123067 (1, 21), Garland Co., Lake Hamilton, T. 3 S., R. 20 W.;

C. E. Burt; July 6, 1931. 123193 (3, 29–40), Hempstead Co., trib. of Terre Rouge Cr., 5.5 mi. NE. of Hope on U.S. 67; J. D. and R. Y. Black; June 22, 1938. 123230 (3, 28), Garland Co., Gulpha Cr. at jct. with Lake Hamilton, 10 mi. E. of Hot Springs; Black and Black; June 23, 1938. 127842 (8, 19–38), Lincoln Co., Caney Cr., 1 mi. N. of Star City; Black and Black; June 20, 1939. 127885 (1, 16), Bradley Co., Saline R., 5 mi. N. of Warren; Black and Black; June 20, 1939. 128060 (1, 16), Polk Co., trib. of Mountain Fk., 6 mi. SW. of Mena; Black and Black; July 6, 1939. 128106 (1, 36), Howard Co., Holly Cr., one-half mi. SE. of Dierks; Black and Black; July 7, 1939. 128138 (1, 32), Pike Co., Prairie Cr., Murfreesboro; Black and Black; July 7, 1939. 128247 (1, 23), Hempstead Co., Middle Fk. of Bois d'Arc Cr., 5.5 mi. NE. of Fulton; Black and Black; July 12, 1939. 128277 (4, 16–24), Garland Co., Gulpha Cr., 6 mi. SE. of Hot Springs; Black and Black; July 12, 1939.

=*Etheostoma* (*Oligocephalus*) *radiosum radiosum* (Hubbs and Black). See Moore and Rigney (1952).

Poecilichthys zonalis Cope, 1868, Journ. Acad. Nat. Sci. Philadelphia, ser. 2, vol. 6, p. 212, color pl. 24, fig. 1.

Lectotype: ANSP 13799 (♂, 42), Virginia, Holston R.; E. D. Cope; herein selected by Dr. Chu-fa Tsai. D XI–11; A II,7; LL 55; INF 4 +3; POM 10; branchisotegals 5; chest naked; cheeks, opercles, and belly completely covered with scales; 6 dorsal blotches.

Paralectotypes: ANSP 13800–1 (♀, 38; ♂, 47), same locality data as lectotype.

Fowler (1907, p. 524) erroneously designated ANSP 14036 lectotype and ANSP 14037–38 paralectotypes. These specimens are not types of *P. zonalis* but are some of the syntypes of *Hyostoma simoterum* Cope. The color plate accompanying Cope's original description shows clearly that Cope had both *E. zonale* and *E. simoterum* from the Holston. Fowler's figure 8, which is labeled as the type of *P. zonalis*, represents a specimen of *Hyostoma simoterum*.

=*Etheostoma* (*Etheostoma*) *zonale zonale* (Cope).

Poecilosoma erythrogastrum Kirtland, 1854, Annals of Science, includ. Trans. Cleveland Acad. Nat. Sci., vol. 2, no. 1, p. 4.

Syntypes: USNM 1815 (?), Ohio, Rocky R., 7 mi. W. of Cleveland; J. P. Kirtland. We have been unable to locate this collection.

=*Etheostoma* (*Oligocephalus*) *caeruleum caeruleum* Storer. See Knapp (1964).

Poecilosoma transversum Abbott, 1860, Proc. Acad. Nat. Sci. Philadelphia, vol. 12, p. 326.

Lectotype: ANSP 13810 (1, 38), locality unknown; number selected by Fowler (1907, p. 525); specimen herein selected. D X–13; A II,7;

LL 31+15=46; INF 4+3; supratemporal canal complete. Abbott noted that there were no data with the specimens and assumed that they might have come from Lake Superior. This could not be so because *E. caeruleum* does not occur there.

Paralectotypes: ANSP 13811–19 (9, 28–42), same data as lectotype.

=*Etheostoma* (*Oligocephalus*) *caeruleum caeruleum* Storer. See Knapp (1964).

Rheocrypta copelandi Jordan, 1877, U.S. Nat. Mus. Bull. 10, p. 9.

Lectotype: USNM 20143 (♂, 43), Indiana, White R., 5 mi. N. of Indianapolis; Jordan and Copeland; herein selected. D XI–12; A II,9; LL 53; INF 8; POM 10; opercles scaled; cheeks naked. Jordan and Evermann (1896, p. 1046) listed USNM 20143, which contained two specimens, as type; herein further restricted.

Paralectotypes: USNM 197996 (♂, 43), removed from USNM 20143; USNM 23461 (♂, 44); MCZ 24392 (♂, 39), and BMNH 1880. 1.21.36–37 (2 ♂, 43–45); all part of Jordan's material originally "some thirty in number" from the type locality.

=*Percina* (*Cottogaster*) *copelandi* (Jordan).

Richia brevispina Coker, 1926, Bull. Bur. Fish., vol. 42, p. 106, fig. 1.

Holotype: USNM 87411 (♂, 36), North Carolina, Burke Co., Paddy's Cr., just above head of Paddy's Cr. Lake, part of artificial Lake James system near Bridgewater, Catawba drainage; R. E. Coker; August 1922.

Paratypes: USNM 87412 (2, 27–36), same data as holotype.

=*Etheostoma* (*Catonotus*) *flabellare* ssp. See Hubbs (1927) and Myers (1927). [= *E.* (*C.*) *f. brevispina* (Coker) according to Ross and Carico (1963, p. 13)].

Sciaena caprodes Rafinesque, 1818, Amer. Month. Mag. and Critical Rev., vol. 3, no. 5, p. 354.

Types: Type locality—the Ohio River. As Call (1899) noted, Rafinesque did not preserve any of his type material. Examination of a sketch of this species in Rafinesque's notebook (fig. 5) shows that the name is correctly attributed.

=*Percina* (*Percina*) *caprodes caprodes* (Rafinesque).

Ulocentra gilberti Evermann and Thoburn *in* Jordan and Evermann, 1896, U.S. Nat. Mus. Bull. 47, p. 1049.

Holotype: USNM 47531 (1, 38), Tennessee, Clinch R. at Walker's Ford, near Tazewell; B. W. Evermann, J. T. Scovell, and R. R. Gurley; Oct. 12, 1893; figured in Jordan and Evermann (1900, fig. 446).

Paratypes: USNM 125373 (1, 36), orig. BF 285, and SU 1954 (2, 47), same data as holotype. The original description was supposedly based on three specimens, so there may have been an error in the original description. The SU bottle was broken during the 1906 earthquake, so there is also a possibility that another specimen of the same species became mixed with SU 1954.

=*Percina* (*Cottogaster*) *copelandi* (Jordan).

Ulocentra meadiae Jordan and Evermann, 1898, U.S. Nat. Mus. Bull. 47, p. 2852.

Holotype: USNM 48903 (♂, 46), Tennessee, Indian Cr., trib. of Powell R. at Cumberland Gap; R. R. Gurley; Oct. 17, 1893; figured by Jordan and Evermann (1900, fig. 447).

Paratypes: USNM 125623 (♂, 46), same data as holotype; orig. BF 711. The third paratype was sent to SU according to a U.S. Fish Comm. distribution list, but Böhlke (1953) did not list it among the Stanford types, and we were unable to find it there.

=*Etheostoma* (*Boleosoma*) *jessiae* (Jordan and Brayton).

Vaillantia chlorosoma Hay, 1881, Proc. U.S. Nat. Mus., vol. 3, p. 495.

Syntypes: USNM 27428, Mississippi, branch of Tuscumbia R. at Corinth; O. P. Hay; March–April 1880; completely disintegrated and dried by 1937. SU 726 (3 ♀, 37–41), Mississippi, Macon; Hay. Although not listed as types by Böhlke (1953), the data on the label, plus a label reading "cotypes," lead us to believe this is part of the original type material. The original description was based on specimens from the Tuscumbia R. at Corinth, Sandy Cr. at Artesia, and Horsehunter Cr. at Macon. Some of this material was placed in the U.S. National Museum, some in Jordan's collections, and the remainder in the Butler University collection. It seems likely that SU 726 represents material given to Jordan by Hay.

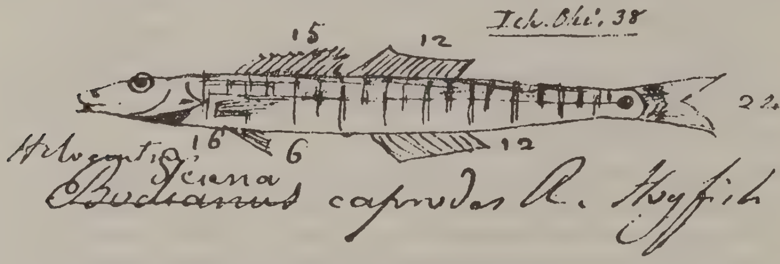

FIGURE 5.—*Sciaena caprodes* Rafinesque (sketch from Rafinesque's notebook).

=*Etheostoma* (*Boleosoma*) *chlorosomum* (Hay).

Villora edwini Hubbs and Cannon, 1935, Misc. Publ. Mus. Zool. Univ. Michigan, no. 30, p. 13, pl. 1, fig. 1.

Holotype: UMMZ 87892 (♂, 37), Florida, Alachua-Columbia Co. line, Santa Fe R. at Poe Springs; E. T. Boardman; Feb. 8, 1928.

Paratypes: UMMZ 107047 (3, 30–35) and USNM 94684 (♀, 33), same data as holotype. UMMZ 101680 (2 ♀, 33–35), same locality; J. D. Kilby and A. F. Carr; Mar. 19, 1934. UMMZ 88685 (1, 25), Georgia, Early Co., trib. of Chattahoochee R., 2 mi. NW. of Jakin; E. P. Creaser and H. R. Becker; Sept. 15, 1929. MCZ 98 (1, ?), "Ga."; Barratt; no longer present in MCZ collection.

=*Etheostoma* (*Villora*) *edwini* (Hubbs and Cannon). See Collette and Yerger (1962).

Villora okaloosae Fowler, 1941, Proc. Acad. Nat. Sci. Philadelphia, vol. 92, p. 242, fig. 12.

Holotype: ANSP 69159 (♀, 24), Florida, Okaloosa Co., Little Rocky Cr., 7 mi. NE. of Niceville on rt. 218 (now Fla. 285); F. Harper; June 20, 1939. Holotype redescribed by Collette and Yerger (1962).

=*Etheostoma* (*Villora*) *okaloosae* (Fowler). See Yerger (1960) and Collette and Yerger (1962).

Checklist of Nominal Species

acuticeps Bailey, *Etheostoma.* (UMMZ)
aesopus Cope, *Boleosoma.* (ANSP?)
alabamae—see *whipplei alabamae.*
anceps Vaillant, *Plesioperca.* (MNHN)
appalachia—see *barratti appalachia.*
arcansanum—see *zonale arcansanum.*
arcus-celestis Crevecoeur, *Etheostoma.* (USNM?)
artesiae Hay, *Poecilichthys.* (USNM)
asprellus Jordan, *Pleurolepis.* (INHS)
asprigenis Forbes, *Poecilichthys.* (SU)
aspro Cope and Jordan, *Alvordius.* (X)
atraque—see *fusiformis atraque.*
atripinnis Jordan, *Arlina.* (USNM)
atromaculata Girard, *Estrella.* (?)
aubeenaubei Evermann, *Etheostoma.* (USNM)
aurantiacus Cope, *Cottogaster.* (ANSP)
australe Jordan, *Etheostoma*—see *fasciatus, Diplesion.*

Barratti Holbrook, *Boleosoma.* (MCZ, UMMZ)
barratti appalachia Bailey, *Hololepis.* (UMMZ, CU, DU)
beani Jordan, *Poecilichthys.* (USNM)
beanii Jordan, *Ammocrypta.* (USNM)
bimaculata Haldeman, *Percina.* (USNM?)
binotatum—see *hopkinsi binotatum.*

blennioides Rafinesque, *Etheostoma.* (X)
blennioperca Cope, *Hyostoma.* (ANSP)
blennius Gilbert and Swain, *Etheostoma.* (USNM, SU)
borealis Jordan, *Poecilichthys.* (USNM, SU)
brevipinnis—see *olmstedi brevipinnis.*
brevispina Coker, *Richia.* (USNM)
butlerianus Hay, *Poecilichthys.* (USNM)
burtoni—see *caprodes burtoni.*

caerulea Storer, *Etheostoma.* (MCZ)
camurum Forbes, *Boleosoma.* (USNM, SU, MCZ, UMMZ)
camurus Cope, *Poecilichthys.* (ANSP)
caprodes Rafinesque, *Sciaena.* (X)
caprodes burtoni Fowler, *Percina.* (ANSP)
carbonaria Baird and Girard, *Pileoma.* (USNM, MCZ, UMMZ)
cheneyi Evermann and Kendall, *Cottogaster.* (USNM, SU)
chlorosoma Hay, *Vaillantia.* (USNM, SU)
cinerea Storer, *Etheostoma.* (?)
clara Jordan and Meek, *Ammocrypta.* (USNM, SU, UMMZ)
collis Hubbs and Cannon, *Hololepis.* (UMMZ)
collis lepidinion Collette, *Etheostoma.* (USNM, CU, DU)
coosae Fowler, *Poecilichthys.* (ANSP)
copelandi Jordan, *Rheocrypta.* (USNM, MCZ, BMNH)
cragini Gilbert, *Etheostoma.* (USNM)
crassus Jordan and Brayton, *Alvordius.* (USNM)
cumberlandicum Jordan and Swain, *Etheostoma.* (USNM)
cyanorum—see *radiosus cyanorum.*
cymatogramma Abbott, *Pileoma.* (ANSP)
cymatotaenia Gilbert and Meek, *Etheostoma.* (USNM, SU)

davisoni Hay, *Etheostoma.* (USNM)
ditrema Ramsey and Suttkus, *Etheostoma.* (TU, USNM, MCZ, ANSP, CU, SU, UMMZ)
duryi Henshall, *Etheostoma.* (X)

edwini Hubbs and Cannon, *Villora.* (UMMZ, USNM, MCZ)
effulgens Girard, *Arlina.* (USNM)
elegans Girard, *Boleichthys.* (MCZ)
elegans Hay, *Nanostoma.* (USNM, SU)
eos Jordan, *Boleichthys.* (USNM)
erizonus—see *euzonus erizonus.*
erochrous Cope, *Hololepis.* (MNHN)
erythrogastrum Kirtland, *Poecilosoma.* (USNM?)
eulepis—see *nigrum eulepis.*
euzonus erizonus Hubbs and Black, *Poecilichthys.* (UMMZ)
euzonus euzonus Hubbs and Black, *Poecilichthys.* (UMMZ, USNM)

evermanni Moenkhaus, *Hadropterus.* (USNM)
evides Jordan and Copeland, *Alvoridus.* (USNM, MCZ)
exilis Girard, *Boleichthys.* (USNM, MCZ, UMMZ)

fasciatus Girard, *Catonotus.* (USNM, MCZ)
fasciatus Girard, *Diplesion.* (MCZ, UMMZ)
flabellaris Rafinesque, *Etheostoma.* (X)
fonticola Jordan and Gilbert, *Alvarius.* (USNM)
fontinalis Rafinesque, *Etheostoma.* (X)
formosa Henshall, *Etheostoma.* (?)
fricksia Hildebrand, *Etheostoma.* (USNM)
fusiforme Girard, *Boleosoma.* (USNM, MCZ, UMMZ)
fusiformis atraque Hubbs and Cannon, *Hololepis.* (UMMZ, USNM)
fusiformis insulae Hubbs and Cannon, *Hololepis.* (MCZ, UMMZ)
fusiformis metae-gadi Hubbs and Cannon, *Hololepis.* (USNM, UMMZ)

gelida Hay, *Ammocrypta.* (USNM)
gilberti Evermann and Thoburn, *Ulocentra.* (USNM, SU)
gracile Girard, *Boleosoma.* (USNM, MCZ)
grahami Girard, *Oligocephalus.* (MCZ)
güntheri Eigenmann and Eigenmann, *Etheostoma.* (BMNH)
gutselli Hildebrand, *Poecilichthys.* (USNM)

hildebrandti Evermann and Clark, *Etheostoma.* (USNM)
histrio Jordan and Gilbert, *Etheostoma.* (USNM, SU)
hopkinsi Fowler, *Poecilichthys.* (ANSP)
hopkinsi binotatum Bailey and Richards, *Etheostoma.* (CU, UMMZ, USNM)
humeralis Girard, *Oligocephalus.* (USNM, MCZ)

inscriptus Jordan and Brayton, *Nothonotus.* (USNM)
insulae—see *fusiformis insulae.*
iowae Jordan and Meek, *Etheostoma.* (SU)

jessiae Jordan and Brayton, *Poecilichthys.* (?)
jordani Gilbert, *Etheostoma.* (USNM, CAS, BMNH, UMMZ)
juliae Meek, *Etheostoma.* (USNM, SU)

kanawhae Raney, *Poecilichthys.* (UMMZ, CU, USNM)
Kennicotti Putnam, *Catonotus.* (USNM, MCZ, UMMZ)

lenticula Richards and Knapp, *Percina.* (CU, TU, USNM, UMMZ)
leonensis Girard, *Oligocephalus.* (MCZ)
lepida Baird and Girard, *Boleosoma.* (USNM, MCZ, UMMZ)
lepidinion—see *collis lepidinion.*
lepidogenys Evermann and Kendall, *Etheostoma.* (USNM)

lineolatus Agassiz, *Catonotus*. (MCZ, UMMZ, MNHN)
Linsleyi Storer, *Etheostoma*. (?)
longimana Jordan, *Etheostoma*. (MCZ, USNM, UMMZ)
luteovinctum Gilbert and Swain, *Etheostoma*. (USNM, SU)
lynceum Hay, *Etheostoma*. See *elegans*, *Nanostoma* for types.

macrocephalum Cope, *Etheostoma*. (ANSP)
maculata Kirtland, *Etheostoma*. (?)
maculaticeps Cope, *Boleosoma*. (ANSP)
maculatum Agassiz, *Boleosoma*. (USNM)
maculatus Girard, *Alvordius*. (USNM?)
maculatus Girard, *Hadropterus*. (USNM)
manitou Jordan, *Percina*. (USNM)
mariae Fowler, *Belophlox*. (ANSP)
maxinkuckiensis Evermann, *Hadropterus*. (USNM)
meadiae Jordan and Evermann, *Ulocentra*. (USNM)
mesaeus Cope, *Poecilichthys*. (ANSP)
metae-gadi—see *fusiformis metae-gadi*.
microperca Jordan and Gilbert, *Etheostoma*. See *punctulata*, *Microperca* for types.
micropterus Gilbert, *Etheostoma*. (USNM)
minima Haldeman, *Perca*. (ANSP)
montanus—see *whipplii montanus*.
montuosa—see *notogramma montuosa*.
moorei Raney and Suttkus, *Etheostoma*. (CU, TU, USNM, UMMZ, UK)
mutatum Vaillant, *Boleosoma*. See *maculatum*, *Boleosoma* for types.

nasutus Bailey, *Hadropterus*. (UMMZ, USNM)
nebulosa Haldeman, *Perca*. (ANSP)
nevisense Cope, *Etheostoma*. (ANSP?)
Newmanii Agassiz, *Hyostoma*. (USNM, MCZ, UMMZ)
nianguae Gilbert and Meek, *Etheostoma*. (USNM, SU)
nianguae spilotum Gilbert, *Etheostoma*. (USNM, SU)
nigra Rafinesque, *Etheostoma*. (X)
nigrofasciata raneyi Crawford, *Percina*. (CU, USNM)
nigrofasciatus Agassiz, *Hadropterus*. (MCZ, USNM, UMMZ)
nigrofasciatus westfalli Fowler, *Hadropterus*. (ANSP)
nigrum eulepis Hubbs and Greene, *Boleosoma*. (UMMZ, USNM, UW)
notogramma montuosa Hogarth and Woolcott, *Percina*. (USNM, UMMZ, CU, UR, VPI)
notogrammus Raney and Hubbs, *Hadropterus*. See *maculatus*, *Hadropterus* for types.
nuchale Howell and Caldwell, *Etheosoma*. (UMMZ, USNM, TU, UAIC)

obeyense Kirsch, *Etheostoma.* (USNM, SU, BMNH)
okaloosae Fowler, *Villora.* (ANSP)
oligoporus—see *thermophilus oligoporus.*
olmstedi Storer, *Etheostoma.* (MCZ)
olmstedi brevipinnis Cope, *Boleosoma.* (ANSP)
osburni Hubbs and Trautman, *Poecilichthys.* (UMMZ, USNM, OSM)
ouachitae Jordan and Gilbert, *Etheostoma.* (USNM, UMMZ)
oxyrhynchus Hubbs and Raney, *Hadropterus.* (UMMZ, USNM)

pagei Meek, *Etheostoma.* (USNM)
pallididorsum Distler and Metcalf, *Etheostoma.* (KU, USNM, UMMZ, CU)
palmaris Bailey, *Hadropterus.* (UMMZ, USNM)
paludosus—see *radiosus paludosus.*
palustris Gilbert, *Poecilichthys.* (USNM)
pantherinus Moore and Reeves, *Hadropterus.* (UMMZ, OAM, MCZ, USNM)
parvipinne Gilbert and Swain, *Etheostoma.* (USNM)
pellucidus Agassiz, *Pleurolepis.* (USNM, MCZ, UMMZ)
peltatum Stauffer, *Etheostoma.* (ANSP)
perlongum Hubbs and Raney, *Boleosoma.* (UMMZ)
phlox Cope, *Boleosoma.* (ANSP)
phoxocephalum Nelson, *Etheostoma.* (UMMZ)
podostemone Jordan and Jenkins, *Etheostoma.* (USNM)
potsii Girard, *Aplesion.* (MCZ)
proeliaris Hay, *Microperca.* (USNM)
pulchellus Girard, *Oligocephalus.* (MCZ)
punctulata Putnam, *Microperca.* (USNM, MCZ, UMMZ).
punctulatus Agassiz, *Poecilichthys.* (MCZ)
putnami Jordan and Gilbert, *Cottogaster.* (USNM)

quapella Eigenmann and Eigenmann, *Etheostoma.* (BMNH)
quiescens Jordan, *Poecilichthys.* (USNM)

radiosus—see *whipplii radiosus.*
radiosus cyanorum Moore and Rigney, *Poecilichthys.* (UMMZ, OAM, MCZ, USNM, UOMZ)
radiosus paludosus Moore and Rigney, *Poecilichthys.* (UMMZ, MCZ, UOMZ, OAM, USNM)
raneyi—see *nigrofasciata raneyi.*
rex Jordan and Evermann, *Etheostoma.* (USNM)
roanoka Jordan and Jenkins, *Etheostoma.* (USNM, SU, CU, MCZ)
rufilineatus Cope, *Poecilichthys.* (ANSP)
rupestre Gilbert and Swain, *Etheostoma.* (USNM)

sagitta Jordan and Swain, *Poecilichthys.* (USNM?)

saludae Hubbs and Cannon, *Hololepis.* (UMMZ, CM, FMNH)
sanguifluus Cope, *Poecilichthys.* (ANSP)
saxatilis Hay, *Poecilichthys.* (USNM)
scierus Swain, *Hadropterus.* (USNM)
scierus apristis Hubbs and Hubbs, *Hadropterus.* (UMMZ, USNM, TNHC, FMNH, OAM, TAMC, SU)
scierus serrula Jordan and Gilbert, *Hadropterus.* (USNM)
sciotense Osburn and Williamson, *Etheostoma.* (USNM)
scovellii Woolman, *Etheostoma.* (USNM, BMNH, CAS)
sellaris Radcliffe and Welsh, *Hadropterus.* (USNM)
semifasciatum DeKay, *Pileoma.* (?)
serrifer Hubbs and Cannon, *Hololepis.* (UMMZ, USNM, CM)
serrula—see *scierus serrula.*
shumardi Girard, *Hadropterus.* (USNM)
simoterum Cope, *Hyostoma.* (ANSP, USNM, MNHN)
spectabilis Agassiz, *Poecilichthys.* (UMMZ, MCZ, USNM)
spillmani Hay, *Hadropterus.* (USNM)
spilotum—see *nianguae spilotum.*
squamatus Gilbert and Swain, *Etheostoma.* (USNM)
squamiceps Jordan, *Etheostoma.* (USNM)
stigmaeum Jordan, *Boleosoma.* (ANSP)
susanae Jordan and Swain, *Boleosoma.*(USNM)
swaini Jordan, *Poecilichthys.* (USNM)
swannanoa Jordan and Evermann, *Etheostoma.* (USNM, SU, UMMZ)

tessellata Storer, *Etheostoma.* (?)
tessellatum DeKay, *Boleosoma.* (?)
tessellatus Jordan, *Hadropterus.* (USNM)
tetrazonus Hubbs and Black, *Poecilichthys.* (UMMZ)
thalassinus Jordan and Brayton, *Nothonotus.* (USNM, SU, MCZ, BMNH)
thermophilus Hubbs and Cannon, *Hololepis.* (UMMZ, USNM)
thermophilus oligoporus Bailey and Frey, *Hololepis.* (UMMZ, DU)
tippecanoe Jordan and Evermann, *Etheostoma.* (USNM)
transversum Abbott, *Poecilosoma.* (ANSP)
trisella Bailey and Richards, *Etheostoma.* (UMMZ)
tuscumbia Gilbert and Swain, *Etheostoma.* (SU, BMNH, UMMZ, USNM)

uranidea Jordan and Gilbert, *Etheostoma.* (USNM)

variata Kirtland, *Etheostoma.* (?)
verecundum Jordan and Evermann, *Etheostoma.* (USNM)
versicolor Agassiz, *Poecilichthys.* (USNM)
vexillare Jordan, *Boleosoma.* (?)
vigil Hay, *Ioa.* (USNM)

vinctipes Jordan, *Nanostoma.* (USNM)
virgatus Jordan, *Poecilichthys.* (USNM, UMMZ)
vitreus Cope, *Poecilichthys.* (ANSP?)
vivax Hay, *Ammocrypta.* (USNM)
vulneratus Cope, *Poecilichthys.* (ANSP)

warreni Girard, *Boleichthys.* (MCZ)
westfalli—see *nigrofasciatus westfalli.*
whipplei alabamae Gilbert and Swain, *Etheostoma.* (USNM, SU)
whipplii Girard, *Boleichthys.* (MCZ)
whipplii montanus Hubbs and Black, *Poecilichthys.* (UMMZ, USNM)
whipplii radiosus Hubbs and Black, *Poecilichthys.* (UMMZ, USNM)
wrighti McCormick, *Etheostoma.* (?)

zebra Agassiz, *Pileoma.* (MCZ, UMMZ)
zonale arcansanum Jordan and Gilbert, *Etheostoma.* (USNM, UMMZ)
zonalis Cope, *Poecilichthys.* (ANSP)
zonifer Hubbs and Cannon, *Hololepis.* (UMMZ)

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U.S. GOVERNMENT PRINTING OFFICE:1966

REQUEST FOR A RULING TO CORRECT HOMONYMY IN NAMES OF THE FAMILY-GROUPS BASED ON *PLETHODUS* (PISCES) and *PLETHODON* (CAUDATA). Z.N.(S.) 1803

By Bruce B. Collette (*Bureau of Commercial Fisheries Ichthyological Laboratory, U.S National Museum, Washington, D.C.*) and
David B. Wake (*Department of Anatomy, University of Chicago, Chicago, Illinois*)

When homonymy exists between family-group names based on similar but not identical names of type-genera, the case is to be referred to the International Commission (1964, International Code of Zoological Nomenclature, Art. 55(a)). A case of homonymy involves the family-group name PLETHODONTIDAE, in current use both in Amphibia (Caudata) and Pisces (Osteoglossiformes).

Plethodon Tschudi, 1838, is the type-genus of the family-group name PLETHODONTIDAE Gray, 1850. This family, the lungless salamanders, consists of 23 genera and about 185 species limited to the New World except for two species in southern Europe (Wake, 1966).

Plethodus Dixon, 1850, is the type-genus of the family-group name PLETHODIDAE Loomis, 1900. This family of fossil osteoglossoid fishes consists of about eight genera known from the Upper Cretaceous of Europe, North Africa, and North America (Bardack, 1965). Loomis (1900) clearly proposed a new family PLETHODIDAE for *Plethodus*, *Thryptodus*, and *Pseudothryptodus*, but for some inexplicable reason he introduced the teleost section of his paper with " Plethodidae A. S. Woodward." As a result several authors (e.g., Hay, 1929) have credited Woodward with authorship of the family PLETHODIDAE.

In his 1902 catalogue, Hay referred to Loomis (1900) as " Plethodidae, part " under OSTEOGLOSSIDAE. But then in his second edition (1929), he used the heading " Plethodontidae Woodward " and credited the description of the family to Woodward, 1912, even though he again listed Loomis (1900) with the notation PLETHODIDAE. The Zoological Record for 1936 used PLETHODONTIDAE as did Weiler (1935) and Stromer (1936). Most other workers have used either PLETHODIDAE (Berg, 1940, 1955; Bertin and Arambourg, 1957; Bardack, 1965) or THRYPTODONTIDAE (described by Jordan, 1923 : 119, as a substitute name) to avoid homonymy with the salamander family but several recent authors (e.g. Romer, 1945; Greenwood et al., 1966) have used PLETHODONTIDAE for the fossil fish family. Romer (1966) used THRYPTODONTIDAE with PLETHODONTIDAE in parentheses and on page 63 used only the former.

Both generic names, *Plethodon* and *Plethodus*, result in the family name PLETHODONTIDAE because *odon* is a variant of *odous* and they each have the genitive *odontos* (Brown, 1954). Because the salamander family is much larger and far better known to both laymen and specialists than the fossil fish family, it seems most reasonable to continue to use PLETHODONTIDAE for the salamanders. Also, two other names have been used for the fossil fishes, the incorrectly formed PLETHODIDAE and the substitute name THRYPTODONTIDAE. PLETHODIDAE is the earlier name and has been used more often so the Commission is requested:

Bull. zool. Nomencl., Vol. 24, Part 4. September 1967.

(1) to rule under the plenary powers that PLETHODIDAE is to be accepted as the correct spelling of the family-group name based on *Plethodus* Dixon, 1850;

(2) to place the following generic names on the Official List of Generic Names in Zoology:
  (a) *Plethodon* Tschudi, 1838 (:92) (gender : masculine), type-species, by subsequent designation by Bibron (*in* Bonaparte, 1839, *Icon. Fauna Ital.* **2** (26), sign. 131**, *Euproctus platycephalus* [4]) in proposing *Phatnomatorhina* as a substitute name for *Plethodon*, *Salamandra glutinosa* Green, 1818 (Caudata);
  (b) *Plethodus* Dixon, 1850 (:394) (gender : masculine), type-species, by subsequent designation by Woodward, 1899, *Plethodus expansus* Dixon, 1850 (Pisces);

(3) to place the following specific names on the Official List of Specific Names in Zoology:
  (a) *glutinosa* Green, 1818 (:357), as published in the binomen *Salamandra glutinosa* (type-species of *Plethodon* Tschudi, 1838) (Caudata);
  (b) *expansus* Dixon, 1850 (:394), as published in the binomen *Plethodus expansus* (type-species of *Plethodus* Dixon, 1850) (Pisces);

(4) to place the following family-group names on the Official List of Family-Group Names in Zoology:
  (a) PLETHODONTIDAE Gray, 1850 (:31) (type-genus *Plethodon* Tschudi, 1838) (Caudata);
  (b) PLETHODIDAE Loomis, 1900 (: 229) (type-genus *Plethodus* Dixon, 1850) (Pisces);

(5) to place the following family-group name on the Official Index of Rejected and Invalid Family-Group Names in Zoology:
  (a) PLETHODONTIDAE Hay, 1929 (type-genus *Plethodus* Dixon, 1850) (Ruled under the plenary powers to be an incorrect spelling for PLETHODIDAE Loomis 1900) (Pisces).

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Made in United States of America
Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 96, No. 2, 21 April 1967
pp. 134–142

Age and Growth of the Tautog, *Tautoga onitis* (Linnaeus), from Rhode Island

RICHARD A. COOPER

Age and Growth of the Tautog, *Tautoga onitis* (Linnaeus), from Rhode Island

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ABSTRACT

The validity of age determinations from the opercular bone of the tautog (*Tautoga onitis*) is established. An examination of the opercular bone margin over a 1-year period demonstrated that the sharp transition from translucent to opaque bone represents a year mark.

A logarithmic transformation of both fish length and length of the opercular bone was linear. Lengths at annuli were calculated by this relationship. Males grow faster than females in length (548 mm at age 22 compared with 501), but slower in weight (1,716 grams at age 20 compared with 2,094 grams for females). The eviscerated weight of male and female tautog captured in May and June increased as the 2.78 and 3.02 powers of the length. The greatest age of tautog examined was about 34 years. Growth differences among discrete spawning groups from Narragansett Bay were not significant.

INTRODUCTION

The tautog, *Tautoga onitis* (Linnaeus), is a popular marine sport fish of Rhode Island. The age and growth of the tautog has not been studied previously. Tautog scales were not used for age determination because annuli are difficult to discern, scales are often extensively pitted by metacercaria of trematodes (*Cryptocotyl* spp.), and regenerate. The use of opercular bones in age studies is well documented in the literature (Bardach, 1955; LeCren, 1947; and McConnell, 1952). Preliminary work with the opercular bone of the tautog indicated that annular marks were discernible. This study evaluates the dependability of the opercular bone in determining age and growth of the tautog and describes the growth of the species in Rhode Island.

Tautog are restricted to the coastal regions of eastern North America from Nova Scotia to South Carolina and are most abundant between Cape Cod and the Delaware Capes (Bigelow and Schroeder, 1953). Stock identification, migration, and population estimation of the Rhode Island tautog were treated by Cooper (1966). Tautog of Narragansett Bay are limited to Rhode Island's coastal waters. The adults inhabit the bay and inshore waters from early May until late October. During the winter, tautog occupy deeper areas with rugged bottom topography, where they are relatively dormant and forage little for food. Discrete spawning groups that exist in the northern half of the bay during May and June are thoroughly mixed through the remainder of the year. A high percentage of adults return each spring to the same spawning locations in the upper portion of the bay. Tautog reach a weight of 22.5 pounds and a length of 36.5 inches (Bigelow and Schroeder, 1953).

MATERIALS AND METHODS

Fish were collected from May 1961 to October 1965 from Narragansett Bay and the adjacent Rhode Island coastal waters. Samples of two discrete spawning groups were obtained with otter trawls during May and June 1961 (Figure 1). Additional male and female tautog were selectively captured by skin divers. Males are easily distinguished from females by their more pronounced mandibles (Figure 2). Sex, total length, and eviscerated body weight were recorded. The right and left opercular bones were dissected and boiled in water for 2 minutes. The opercular bones were then cleaned by brushing and allowed to dry 48 hours. Ages were determined by holding the bones before a light and counting annular rings. Age readings from right and left opercular bones usually were the same. If ages were different, the bones were reexamined to assign an age. Each pair of bones was reread 6 months later.

The opercular bone of the tautog is laterally compressed and triangular. The outer surface of the bone is convex; the inner surface is concave. Both surfaces taper posteriorly to

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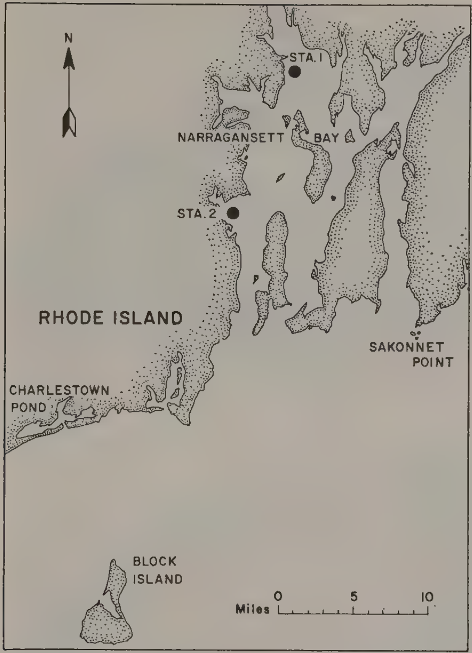

FIGURE 1.—Narragansett Bay, showing sampling stations.

TABLE 1.—*Comparison of two age readings of tautog by the same person*

Age (yrs.)	Number of bone pairs	Duplicate readings matching first	Percentage agreement
I	44	43	98
II	46	44	96
III	50	43	86
IV	45	45	100
V	73	68	93
VI	79	73	92
VII	59	57	97
VIII	42	41	98
IX	26	21	81
X	34	28	82
XI	34	28	82
XII	18	15	83
XIII	22	15	68
XIV	19	14	74
XV	12	6	50
XVI	12	9	75
XVII	10	6	60
XVIII	11	7	64
XIX	10	10	100
XX	5	3	60
XXI	4	2	50
Total or average	655	578	88

a thin edge. The dorsal margin of the bone is thick and opaque; the ventral margin is relatively thin and has a pronounced cleft. Alternating opaque and translucent zones can be seen in transmitted light (Figure 3). I have determined that the sharp transition from translucent to opaque is the annual growth mark; annual growth equals an opaque plus a translucent zone.

The center of growth for the bone and the origin for measurements is the center of the articular apex (Figure 4). This location corresponds to the one used by Bardach (1955) on the yellow perch, *Perca flavescens*, by LeCren (1947) on *Perca fluviatilis*, by McConnell (1952) on the carp, *Cyprinus carpio.*

To measure distance between annuli the opercular bone was softened in boiling water, and a band was cut from it with metal cutting shears. The band included a section of the bone from its articular apex to the posterior margin, in which an imaginary line cut the annular growth marks at approximately right angles (Figure 4). The band was flattened between two glass slides and projected on the screen of an Eberbach scale projector (magnification, 26.5×). Measurements were made from the origin to succeeding annuli and to the posterior margin of the bone. When an annulus was not clearly defined, as was often true with the first annulus, its measurement was omitted, but it was counted in the assignment of age.

COMPARISON OF OPERCULAR BONE READINGS

The agreement between first and second age determinations by the same person was good (Table 1). Of the 77 readings that differed, 74 disagreed by 1 year and 3 (all for fish older than 15 years) by 2 years. The average agreement was 92% for fish 1–12 years old and 69% for fish 13–21 years old.

VALIDATION OF ANNULUS

The most abundant, and most available throughout the year, age groups of tautog sampled, V and VI, were used to determine the time of annulus formation after the method of Nose, Tomomatsu, Mimura, and Hiyama (1955). Measurements of the opercular bones were made from the origin to the posterior margin (R) and to the last annular growth mark (A). The difference between these two measurements was considered the growth increment since the last annulus was formed. This growth increment should be at a maximum just before and at a minimum just after

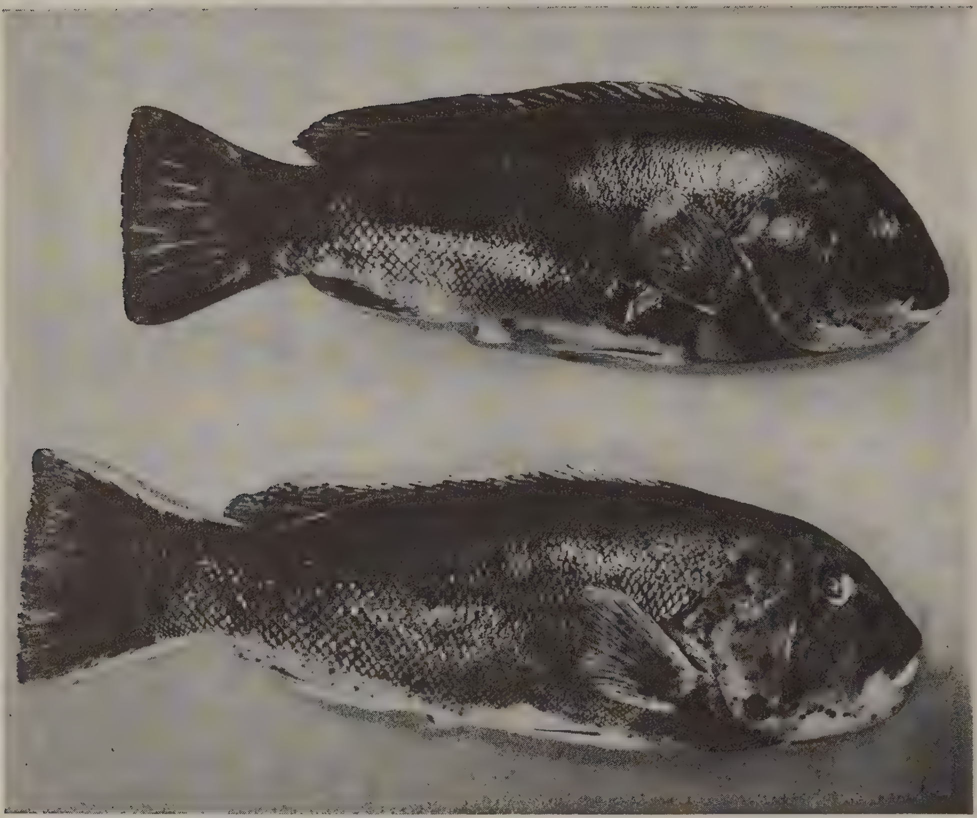

FIGURE 2.—Sexual dimorphism in the tautog. The male (bottom) has more pronounced mandibles than the female (top).

the formation of the last annulus. Figure 5 notes the relation between the absolute growth increment (R-A) and date of capture of the fish. Annulus formation occurs during middle or late May. Formation of the annulus, which marks a resumption of growth, coincides with the time of spawning. Adults on the spawning grounds showed new growth during the spawning period. The data of Figure 5 further suggest that only one annulus is formed per year, the marginal increments increased progressively through the summer and fall to attain values corresponding to those just before the start of new growth.

Somewhat indirect evidence that the annulus is in fact a year mark comes from the comparison of the observed absolute growth increments of recaptured tagged fish with the expected increments (Table 2). Expected increments, determined by back calculation, for both male and female tautog agreed reasonably well with the observed increments.

BODY-BONE RELATION

The relation of the growth of any structure used for the estimation of length of fish in its earlier years must be known if back calculations of length at different ages are to be accurate. The relation of body length (L) to length of the opercular bone (R) was calculated for males and females; each was linear when both variables were transformed to common logarithms. Differences between the Y (log L) intercepts and the slopes of these lines were not significant at the 95% confidence

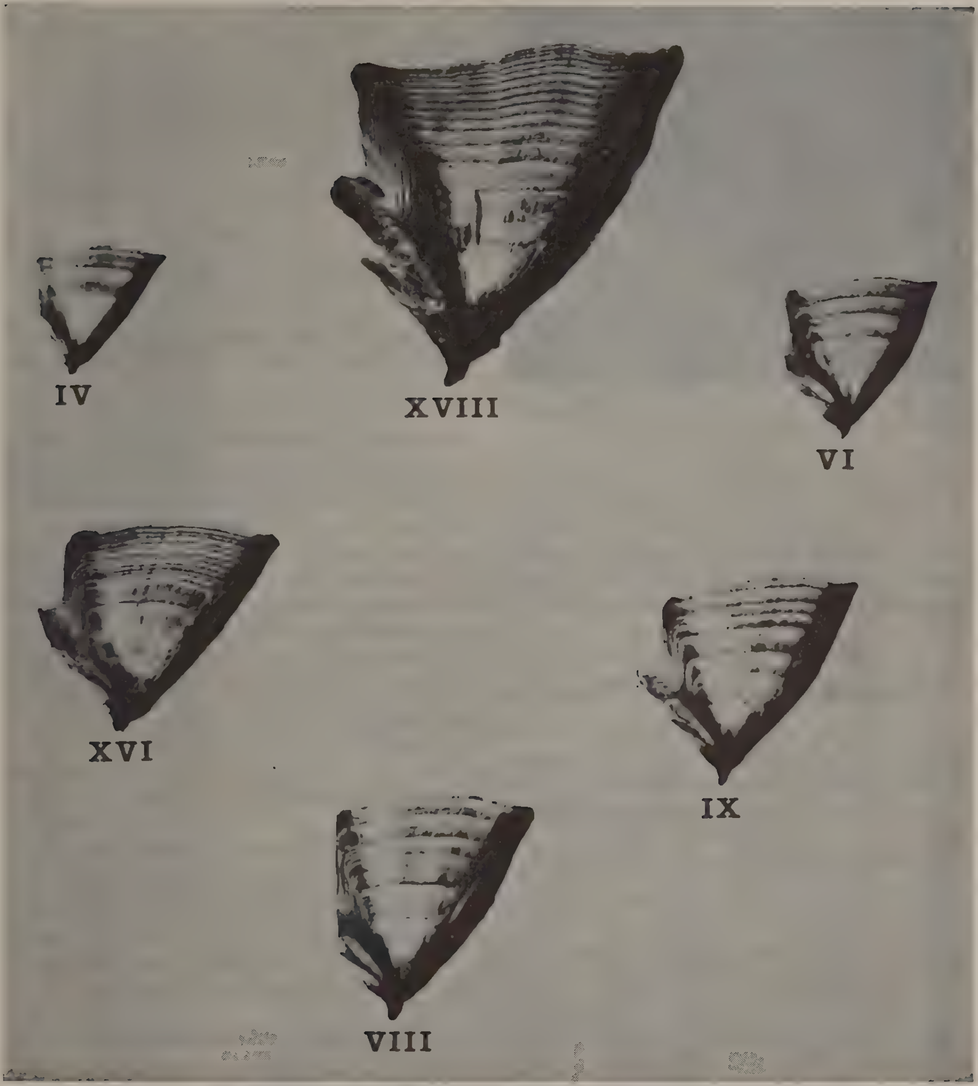

FIGURE 3.—Opercular bones from tautog of different ages.

level; accordingly the data for the sexes were combined (Figure 6) to obtain the equation, $\log L = 1.24036 + 0.89986 \log R$. This relation was obtained from 335 male and female tautog ranging from 50 to 620 mm long.

All calculations were made from a formula which was derived from the above regression line and which gives solutions that are not influenced by magnification of the bone length measurements or their deviation from regression. Let us establish L_n and R_n as fish length and bone length values for the nth year and L_t and R_t as the length values at capture. Then

$$\log L_n = \log C + N \log R_n \qquad (1)$$

and,

$$\log L_t = \log C + N \log R_t \qquad (2)$$

Subtraction of equation (2) from equation (1) gives

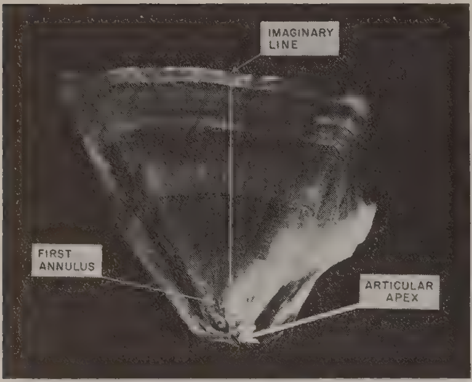

FIGURE 4.—Opercular bone from a IV-group tautog collected in early June.

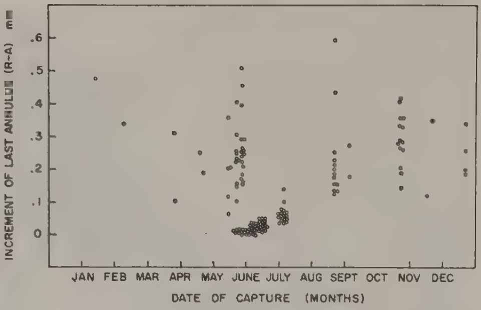

FIGURE 5.—Growth increment beyond the last annulus and date of capture for V- and VI-group tautog.

$$\log L_n = \log L_t + N\,(\log R_n - \log R_t) \quad (3)$$

where $N = 0.89986$, the slope of the body-bone regression. Calculated lengths were obtained by substituting the mean radial measurements for an age group into equation 3.

LENGTH-WEIGHT RELATION

The general parabola, $W = cL^n$, where W = weight, L = total length, and c and n are empirically estimated constants has been used to describe the length-weight relation of numerous species of fish. Determination of the length-weight relations of tautog (Figure 7), based on data from 102 females and 81 males sampled during June 1961, may not be accurately descriptive for other times of the year. The length-weight equations, determined by fitting a straight line to the logarithms of the lengths and weights, are:

$$\log W = -4.35670 + 2.77660 \log L, \qquad \text{(males)}$$

and $\log W = -4.80357 + 3.01607 \log L$, (females)

where W = body weight (excluding viscera) in grams and L = total length in millimeters. The value of n indicates that body weight (eviscerated) increases approximately as the cube of the length for females and less rapidly than the cube of the length for males.

TABLE 2.—*Comparison of observed and expected growth increments of tagged tautog*

Fish length (mm)	Sex	Age	Time at large (yrs)	Increase in length (mm)		
				Observed	Expected[1]	Difference
371	M	VI	1	47	36	+11
290	F	VI	2	81	73	+8
414	M	VII	1	26	32	—6
395	M	VII	1	22	32	—7
352	M	VII	2	63	68	+5
382	F	VII	1	30	28	+2
285	F	VII	1	11	28	—17
305	F	VII	1	9	28	—19
362	M	VII	2	48	68	—20
407	M	VIII	1	18	36	—18
355	M	VIII	1	13	36	—23
381	M	VIII	1	26	36	—10
345	F	VIII	1	10	28	—18
388	F	VIII	1	15	28	—13
365	F	VIII	1	10	28	—18
444	F	VIII	1	18	28	—10
485	M	IX	1	25	31	—6
366	M	IX	1	16	31	—15
359	F	IX	1	10	26	—16
366	F	X	2	33	48	—15
407	M	X	1	12	23	—11
411	F	X	2	50	48	+2
386	M	XI	1	18	21	—3
392	F	XII	1	18	14	+4
479	F	XII	2	35	36	—1
444	F	XIII	1	16	11	+5
410	F	XIV	1	3	7	—4
426	F	XIV	1	16	7	+9
509	M	XVI	1	5	7	—2
436	F	XVII	1	6	4	+2
Average		IX	1.2	23.7	30.9	—6.8

[1] Calculated grand average increment of length, from Tables 3 and 4.

CALCULATED GROWTH IN LENGTH

The average calculated lengths for males and females from different stations exhibited no significant differences; the fish from stations 1 and 2 were combined along with those taken at other locations in Narragansett Bay, for the preparation of Tables 3 and 4. Calculated lengths for males exceeded those for females beyond the first year.

The calculated lengths for male and female tautog exhibited no clear trends of systematic change with increase in age of the fish from raw data on which the calculations were based. The discrepancies among calculated growth

TABLE 3.—*Calculated total lengths (millimeters) of male tautog from Rhode Island, 1961–65 collections combined.* [*The measurement of the 1st annulus for XXI- to XXVII-group fish was omitted*]

Age group	No. of fish	Length at capture	Length at end of year of life																										
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
I	81	75	54																										
II	103	155	59	130																									
III	107	215	60	138	200																								
IV	106	258	59	130	203	242																							
V	103	305	59	138	201	246	293																						
VI	91	340	60	125	205	252	299	334																					
VII	77	371	59	131	198	254	288	325	358																				
VIII	59	412	61	139	203	260	287	329	363	400																			
IX	47	442	63	136	208	248	297	331	365	407	435																		
X	42	463	58	122	207	246	295	343	368	404	438	456																	
XI	36	491	60	139	209	250	291	335	370	403	431	453	469																
XII	33	502	62	129	191	241	288	322	352	389	424	447	474	487															
XIII	29	500	61	137	198	246	289	331	368	394	426	459	483	494	498														
XIV	25	501	57	132	203	258	297	340	377	413	439	459	476	484	489	495													
XV	17	516	64	126	209	264	315	344	370	409	440	465	484	493	495	502	510												
XVI	19	524	64	135	202	263	316	333	357	389	419	444	459	469	478	490	505	512											
XVII	16	539	67	136	216	260	309	334	363	405	440	464	488	498	502	511	524	530	534										
XVIII	13	527	59	115	177	264	307	328	351	389	418	436	462	479	484	495	506	511	515	517									
XIX	14	530	71	152	205	258	295	320	346	379	406	430	454	475	482	490	502	510	515	521	524								
XX	7	514	68	138	198	240	279	311	340	368	396	420	443	455	457	468	478	482	490	496	505	512							
XXI	9	560	—	137	226	277	330	358	387	417	438	459	473	483	491	500	512	518	523	528	540	545	550						
XXII	14	564	—	94	177	227	285	315	348	389	424	450	465	479	490	504	517	528	535	540	550	553	555	559					
XXIII	6	578	—	120	170	218	267	306	335	367	399	437	458	470	480	495	506	512	536	547	556	562	566	570	573				
XXIV	7	558	—	127	176	222	274	308	338	365	401	425	449	464	470	479	487	497	512	521	538	542	544	546	548	551			
XXV	5	581	—	155	221	256	289	339	372	411	450	469	494	506	514	527	540	550	554	558	561	564	568	570	572	574	577		
XXVI	4	553	—	106	179	224	284	328	374	416	455	475	495	509	513	517	521	525	529	533	536	539	541	544	546	547	549	550	
XXVII	2	590	—	176	234	260	317	351	381	406	440	464	481	498	501	508	518	524	530	545	551	558	563	567	571	574	578	584	588
Grand average calculated length			61	132	201	249	295	330	361	396	427	451	471	484	490	499	510	517	525	531	540	547	555	559	562	562	568	567	588
Increment of average			61	71	69	48	46	35	31	35	31	24	20	13	6	9	11	7	8	6	9	7	8	4	3	0	6	–1	21
Grand average increment of length			60	73	69	48	44	36	32	36	31	23	21	12	6	9	11	7	6	6	8	4	3	3	2	2	3	3	4
Sum of average increment			60	133	202	250	294	330	362	398	429	452	473	485	491	500	511	518	524	530	538	542	545	548	550	552	555	558	562

TABLE 4.—*Calculated total lengths (millimeters) of female tautog from Rhode Island, 1961–65 collections combined.* [*The measurement of the 1st annulus for XX- to XXII-group fish was omitted*]

Age group	No. of fish	Length at capture	Length at end of year of life																					
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
I	70	78	59																					
II	114	139	58	129																				
III	115	212	60	130	196																			
IV	115	256	63	127	195	243																		
V	112	289	63	128	193	237	274																	
VI	110	325	64	131	199	245	285	318																
VII	95	348	61	125	191	238	278	311	336															
VIII	78	377	59	120	187	225	268	295	321	352														
IX	65	390	63	127	183	230	270	309	335	359	383													
X	57	428	64	126	190	237	283	317	350	378	407	426												
XI	45	437	65	132	198	238	279	310	339	365	390	413	433											
XII	39	460	67	134	203	245	286	317	345	374	403	420	447	458										
XIII	33	473	60	128	190	236	275	312	342	370	396	416	439	456	470									
XIV	29	504	69	139	193	235	272	304	338	375	403	439	467	484	494	498								
XV	14	495	67	142	207	263	306	339	368	394	417	442	461	477	484	490	493							
XVI	11	523	63	130	197	242	294	336	371	402	424	447	465	473	490	501	511	520						
XVII	12	470	58	138	182	227	260	285	324	357	385	405	423	438	447	455	459	464	468					
XVIII	7	481	64	134	197	245	288	319	352	372	393	412	425	439	446	458	463	468	474	477				
XIX	8	452	58	122	176	216	253	280	309	333	360	381	397	410	420	429	437	442	444	446	449			
XX	5	494	—	144	210	260	303	330	359	388	410	423	436	451	460	466	471	476	479	482	485	489		
XXI	2	462	—	131	188	248	299	321	346	368	381	390	404	419	428	437	446	450	452	454	457	459	461	
XXII	2	493	—	123	186	223	251	276	300	337	355	377	395	416	426	442	451	461	465	471	478	482	488	491
Grand average calculated length			63	130	193	239	279	310	340	368	393	415	433	447	457	464	466	469	464	466	467	477	474	491
Increment of average			63	67	63	46	40	31	30	28	25	22	18	14	10	7	2	3	–5	2	1	10	–3	17
Grand average increment of length			62	66	65	45	40	33	28	28	26	22	22	14	11	7	6	6	4	3	3	3	4	3
Sum of average increment			62	128	193	238	278	311	339	367	393	415	437	451	462	469	475	481	485	488	491	494	498	501

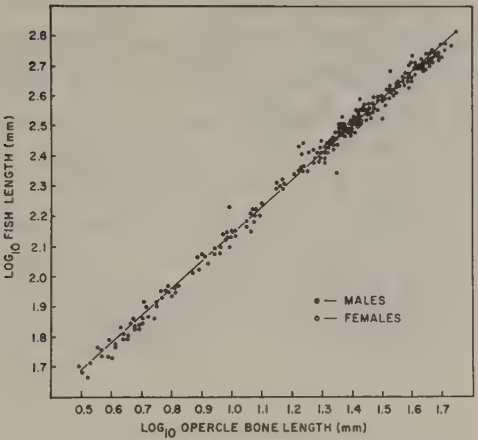

FIGURE 6.—Relation of length of fish to length of opercle bone.

histories of the age groups seemed to be approximately randomly distributed. The discrepancies between the older age groups can be attributed mostly to small numbers of fish.

The estimates of the general growth in length at the bottom of Tables 3 and 4 are based on the grand average calculated lengths and on the successive summation of the grand average increments of length. Lengths computed by the two methods were nearly identical for ages 1 through 20 for males and ages 1 through 14 for females. The largest difference was 26 mm at the end of the 27th year of life for males and 24 mm at the end of the 19th and 21st years of life for females.

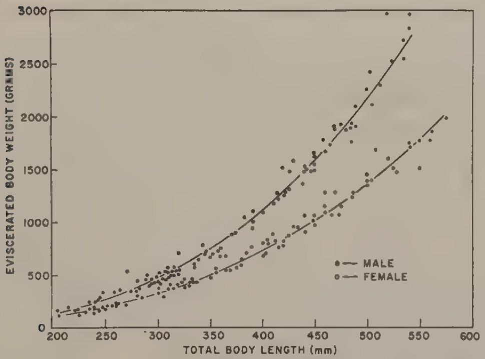

FIGURE 7.—Length-weight relations for male and female tautog. The curve represents the calculated weights and the dots the empirical weights.

TABLE 5.—*Calculated weights (grams) and annual increments of weight of male and female tautog from Rhode Island*

Year of life	Male		Female	
	Calculated weight	Increment	Calculated weight	Increment
1	4	4	4	4
2	35	31	36	32
3	117	82	123	87
4	202	85	231	108
5	314	112	370	139
6	433	119	518	148
7	560	127	672	154
8	728	168	854	182
9	897	169	1,050	196
10	1,036	139	1,238	188
11	1,176	140	1,446	208
12	1,260	84	1,591	145
13	1,304	44	1,711	120
14	1,372	68	1,790	79
15	1,457	85	1,860	70
16	1,513	56	1,932	72
17	1,562	49	1,981	49
18	1,613	51	2,018	37
19	1,681	68	2,056	38
20	1,716	35	2,094	38
21	1,743	27	2,145	51
22	1,769	26	2,184	39
23	1,787	18		
24	1,805	18		
25	1,833	28		
26	1,860	27		
27	1,898	38		

Male and female tautog made their greatest annual growth in length (73 mm and 66 mm) during the second year of life. Beyond the second year the increments decreased to 23 mm (males) and 22 mm (females) in the 10th year and 4 mm (males) and 3 mm (females) in the 20th year.

CALCULATED GROWTH IN WEIGHT

The calculated weights of Table 5 were computed by applying the calculated lengths (sum of the average increments) of Tables 3 and 4 to the appropriate length-weight equations.

The annual increments of weight increased to a maximum of 169 grams for males in the 9th year and 208 grams for females in the 11th year of life, despite the fact that the greatest annual increments of length were attained during the 2nd year. Males require 10 years and females 9 years to reach a body weight (excluding viscera) of 908 grams (2 pounds), which is considered a good fish by rod-and-reel fishermen. Spear fishermen consider a fish of 1,820 grams (4 pounds) to be a good catch; this size is reached in approximately 25 years by males and 15 years by females.

ACKNOWLEDGMENTS

This study was supported by the Marine Resources Program of the Graduate School of Oceanography, University of Rhode Island. Professors S. B. Saila, N. Marshall, and V. H. Hutchison served as members of my thesis committee and offered many valuable suggestions.

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A NEW SPECIES OF *LAGENOPHRYS* (CILIATEA: PERITRICHIDA: LAGENOPHRYIDAE) FROM A MARINE CRAB, *CALLINECTES SAPIDUS*

JOHN A. COUCH

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A NEW SPECIES OF *LAGENOPHRYS* (CILIATEA: PERITRICHIDA: LAGENOPHRYIDAE) FROM A MARINE CRAB, *CALLINECTES SAPIDUS*[1]

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ABSTRACT: *Lagenophrys callinectes* n. sp. (Ciliatea: Peritrichida: Lagenophryidae) is described from the gills of the blue crab (*Callinectes sapidus*) from Chesapeake Bay, Maryland; Chincoteague Bay, Virginia; Beaufort, North Carolina, and Trenchard's Inlet, South Carolina. This species is unique in the structure of the lips of its lorica aperture, and is the first species of *Lagenophrys* reported from a marine brachyuran crab. Aspects of its host-commensal relationship, behavior, and reproduction are reported.

To date 51 species have been described for the sessile peritrich genus *Lagenophrys* Stein, 1852 (Corliss & Brough, 1965; Kane, 1965). The genus is cosmopolitan and its members have been reported as epizoonts on species of different genera of Crustacea.

Lagenophrys metopauliadis Corliss & Brough, 1965 is the only species of the genus described from a true brachyuran crab, *Metapaulias depressus*; an endemic freshwater crab of Jamaica. Kellicott (1894) described, but did not illustrate *Lagenophrys eupagurus* from a marine anomuran crab. To my knowledge, no other species of *Lagenophrys* has been reported from marine crab hosts.

Herein is described the fifty-second species of *Lagenophrys*, the second member of the genus from a true brachyuran host, and the first from a marine brachyuran host. This species was found on the gill lamellae of the commercially important blue crab *Callinectes sapidus* (Fig. 1) and is here named *Lagenophrys callinectes* n. sp.

METHODS

Blue crabs were trapped in Chesapeake Bay crab pots in the manner in which they are harvested for the market from areas (Couch, 1966) in Chesapeake Bay, Maryland and Chincoteague Bay, Virginia. Crabs were collected from North and South Carolina by Mr. George Rees of the U. S. Bureau of Commercial Fisheries Biological Laboratory, Beaufort, North Carolina, in July 1966. The carapaces were broken from the bodies of the crabs, revealing the branchial chambers. Branchiae of the crabs were placed in Petri-plates filled with sea water from the area of collection; then lamellae were teased from branchiae, placed on slides and examined fresh. For the study of living specimens No. 0 cover slips were supported by fragments of No. 1 cover slips to prevent crushing the gill material, and the slide was flooded with sea water to prevent desiccation. Welled slides with hanging-drop preparations were also used. Living specimens were stained with 0.5% concentration of Neutral Red in sea water and 0.5% aqueous Toluidine Blue. These stains were not particularly helpful; the living, unstained specimens proved most useful for behavioral study. Specimens used for morphological studies were fixed in Davidson's (Shaw & Battle, 1957) or Bouin's fixatives and stained with Heidenhain's Iron Alum Hematoxylin or treated with the Bodian (1937) activated protein silver (Protargol) method after bleaching by the method of Honigberg (1947). Most of the stained

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[1] I wish to acknowledge with gratitude valuable suggestions made by Dr. Jiří Lom, Protozoological Laboratory, Prague, Czechoslovakia, and Dr. John O. Corliss, Department of Biological Sciences, University of Illinois at Chicago Circle, Chicago.

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material from the above methods proved excellent. Measurements were made of 50 specimens stained with iron hematoxylin. Means and standard errors for these measurements were determined and are included in the description. Measurements are in microns. Drawings were made with the aid of the camera lucida.

Descriptive Account

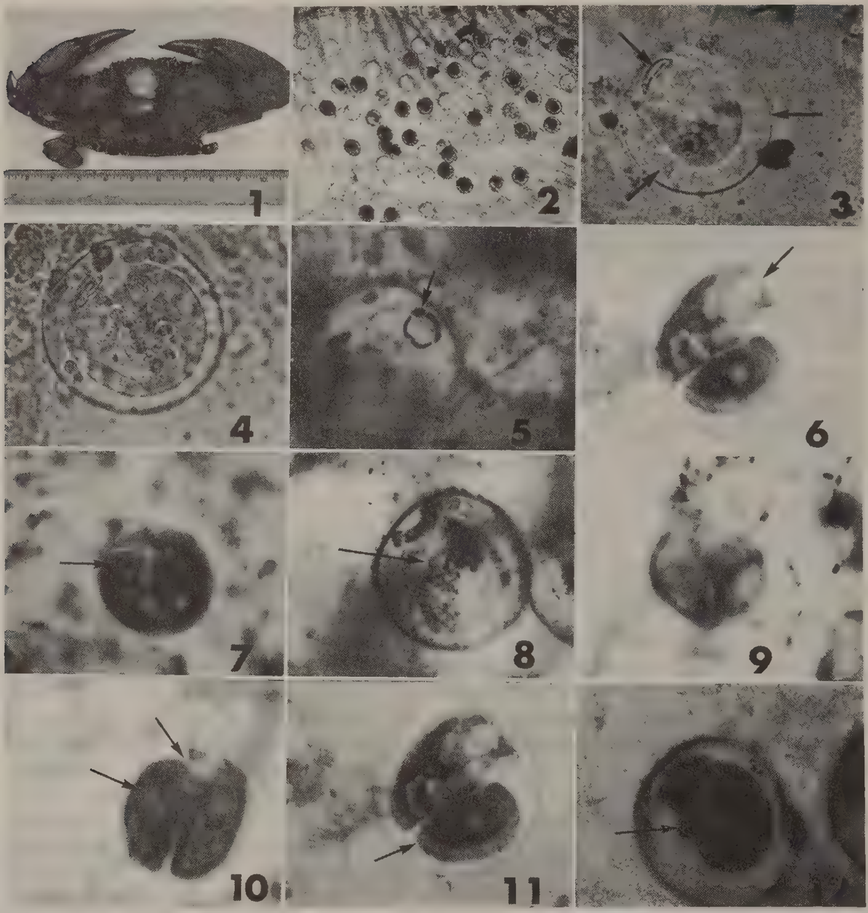
Lagenophrys callinectes n. sp.

In describing the present species, I use terms pertinent to its specialized genus as defined by Corliss (1959) or Kane (1965).

LIVING SPECIMENS: Individuals were found isolated or in heavy concentrations on both surfaces of gill lamellae (Fig. 2). The lorica of *L. callinectes* is nearly round in dorsal and ventral views (Figs. 3, 4), usually colorless, and transparent. In lateral view it forms an incomplete hemisphere (dome), and the ventral surface showed no apparent thickening where it was attached to the host's gill surface. I found no evidence that any kind of mechanical damage had occurred in host tissue as a result of attachment. Occasionally, portions of the gill tissue were heavily colored with a brown amorphous pigmentation and a few loricae of the ciliate were similarly colored around their periphery at the site of attachment.

The oral complex was evident in living specimens. The thickening of the anterior and posterior lips surrounding the loricastome made the lips opaque and easily observed (Figs. 3, 4). Within the body of the living ciliate little detailed structure could be observed with bright-field microscopy. Observable internal structures were the buccal cavity and its ciliature, portions of the cytopharynx, certain food vacuoles and their inclusions, and, occasionally, portions of the macronucleus. It was possible to observe part of the activity of the oral complex, and cytopharynx. This behavior is described in a later portion of this paper.

FIXED AND STAINED SPECIMENS: Most measurements are reported as means, standard errors (parentheses), and ranges. The lorica was only slightly longer, 55.7 (± 3.8) 47.8–59.0, than wide, 53.4 (± 2.5) 47.8–57.0. It was relatively shallow in lateral view, and certain specimens had uneven folds in the lorica surface (Fig. 17). These folds were not visible in dorsal or ventral views of either living or fixed specimens. The lorica possessed a slight anterior crescentic bulge or thickening (Fig. 17). The lorica wall was ca. 0.5–0.7 thick. The mouth or aperture of the lorica was 11.0 (± 0.5) 9.1–11.4 long in its greatest diameter (Fig. 13). The lips surrounding the mouth were in four elements; the lengths of the two anterior elements were greatly unequal (Figs. 5, 13, 14). The left anterior element (dorsal view, Fig. 5; ventral views, Figs. 13, 14, 15) was less than half as long as the right anterior element. The size of the two posterior elements was approximately equal. A notable characteristic of the two anterior lip elements was that their lower distal ends appeared as long formed spines whereas the upper ends were more blunt. This structure formed a notch within which the two distal ends of the posterior lip elements articulated (Fig. 14). The lip elements were situated on a shallow membranous collar the base of which formed the loricastome (Fig. 17). The form of the body of the ciliate within the lorica varied; usually it was round to ovoid, and its surface was striated, but without cilia. The peristomial protoplasm of the ciliate was attached to the lorica around the mouth (Figs. 13, 17, heavily shaded area around oral complex). This area was the only part of the lorica to which the ciliate was attached, and the peristomial protoplasm formed an incompletely attached circle around the mouth within the lorica. In most specimens (living and fixed) a gap or hiatus existed in this circle of protoplasm anterior to the loricastome



FIGS. 1–12. **1.** Blue crab (*Callinectes sapidus*). Rule in inches. **2.** Moderately heavy gill infestation by *Lagenophrys callinectes.* Dark-staining bodies (iron hematoxylin) of ciliates within round loricae. Many empty loricae also. × 100. **3.** Photograph of living *L. callinectes.* Arrows point to lips of aperture, microconjugants, and lorica wall. Figures 3–12 are × 970. **4.** Same as 3. Note two microconjugants within lorica. **5.** Lorica and lips of aperture of *L. callinectes.* Arrow points to shortest lip element. Stained by the Bodian silver protein method. Dorsal view. **6.** Arrow points to hiatus in peristomial protoplasm of *L. callinectes.* Ventral view. **7.** Arrow points to buccal cavity (infundibulum). Note cilia. **8.** Bodian silver stain preparation. Arrow points to kineties within buccal cavity and cytopharynx. **9.** Dividing form. Note "W" form of macronucleus preceding separation of daughter macronuclei. **10.** Telotroch larva (late division) almost separated from residual (parent) body. Arrows indicate point where division begins and position of daughter micronucleus. Dorsal view. **11.** Recently separated residual body and telotroch larva (arrow). **12.** Apparent conjugation of microconjugant (arrow) and macroconjugant.

and lip elements (Figs. 6, 15). In view of my own observations and reports by others (e.g., Corliss & Brough, 1965), that ". . . it (the aperture or mouth) provides the 'escape hatch' for one of the products of binary fission . . .", it is certain that this hiatus in the peristomial protoplasm provides an opening to the mouth for larva(e) of the ciliate to pass through. The buccal cavity (infundibulum) was continuous with the mouth, relatively large, and filled with the adoral membranelle and cilia (Figs. 7, 13). The cavity was in the right side of the ciliate's body (Fig. 16, dorsal view; Figs. 7, 13, ventral views). The myonemes of the adoral zone were found as a compact structure beneath the lower right-hand corner of the buccal cavity (Fig. 16, dorsal view). The myonemes formed a thick structure which stained heavily with the protargol (Bodian) method, and appeared to be basically triangular. Immediately above the surface of the myonemal plate were found the kinetosomes of the haplo- and polykinety (Figs. 8, 16). The kineties, apparently rows of kinetosomes of the buccal cilia as revealed by the protargol silver stain, were 2–3 μ apart at their widest point of separation in the buccal cavity. They made one complete turn within the cavity and could be traced posteriad into the cytopharynx (Figs. 8, 16). The cytopharynx (Fig. 13) began in the lower left corner of the buccal cavity (Fig. 16, dorsal view) and extended as a narrow tube into the middle area of the ciliate's body where large food vacuoles were most abundant (Fig. 13). The polykinety continued to the lower end of the cytopharynx, first as four rows—then as six rows (peniculus) (Fig. 16). A densely argentophilic structure was found which began at the apparent end of the haplokinety and usually appeared to loop down into the lower region of the peniculus (Fig. 16). This may have been the supporting structure(s) in the buccal apparatus as reported by Lom (1963) for several species of peritrichs. Vacuole formation was evident in the cytoplasm of both living and stained specimens. Many food vacuoles contained reserve material which stained very darkly with iron hematoxylin. Willis (1942) reported that the reserve material in the cytoplasm of *L. tattersalli* was apparently lipoid.

The posterior and lateral areas of the ciliate's body were filled by its large macronucleus. The macronucleus ranged from reniform to L-shape, to a horseshoe (U) shape and was 50.8 (± 20.1) 34.2–82.1[2] long by 3.5 (± 2.1) 2.3–5.7 wide (Figs. 7, 13, 15). When stained with iron hematoxylin the macronucleus appeared reticulated and to possess many small vacuoles or lacunae (Fig. 15). The micronucleus was situated in the right concavity of the macronucleus (dorsal view). It rested in the center of a small vacuolated area, was ovoid, and was 2.4 (± 0.6) 1.7–3.4 long (Figs. 13, 15, ventral views).

TYPE HOST: *Callinectes sapidus* Rathbun.

SITE ON HOST: Surfaces of gill lamellae.

LOCALITIES: Chesapeake Bay, Maryland; Chincoteague Bay, Virginia; Beaufort, North Carolina; Trenchard's Inlet, South Carolina.

SPECIMENS DEPOSITED:

Two slides containing type-specimens of *L. callinectes* have been deposited in the International Type-Slide Collection for Ciliate Protozoa currently located at the University of Illinois (but soon to be transferred to the U. S. National Museum, according to Dr. John O. Corliss in a personal communication to the writer). One preparation, containing individuals stained by the protargol silver technique, may be considered as the holotype; the other has been stained with iron hematoxylin. Additional syntypes remain in the writer's personal collection.

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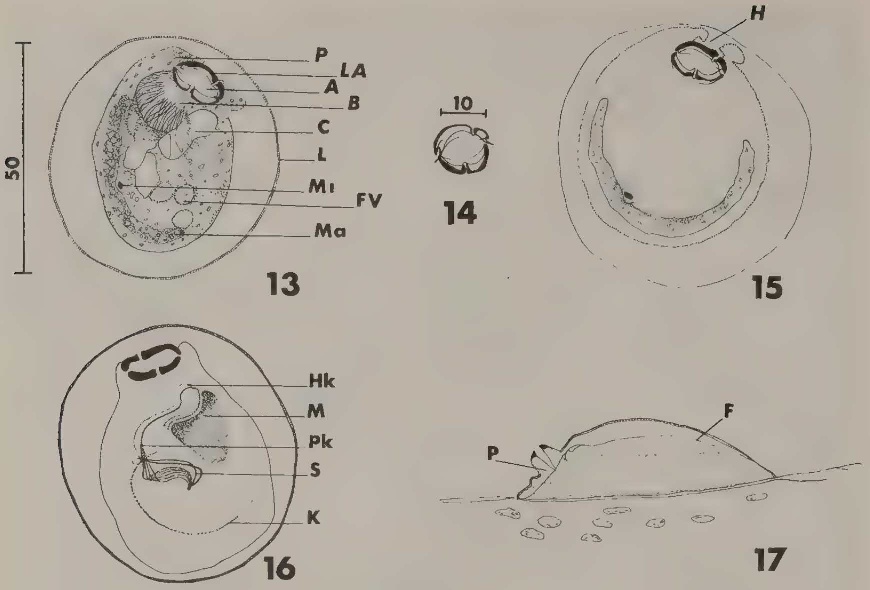
[2] The large standard error reported here for the length of macronucleus reflects the considerable variation in macronuclear lengths in individuals of different stages of maturity and development. The shape or size of the macronucleus of *L. callinectes* is not in itself a consistently strong characteristic for distinguishing this species from others.



FIGS. 13–17. **13**. Camera lucida drawings of *L. callinectes* (except Fig. 16). × 970, and scales in microns; same for all figures. **14**. Detail of lip elements. Ventral view. **15**. Lorica outline showing relative form and position of macronucleus and micronucleus. Ventral view. **16**. Detail of Bodian silver stained specimen showing positions of haplokinety, polykinety and myonemes. Dorsal view. **17**. Lateral view of *L. callinectes* on gill surface of host.

List of abbreviations: P, peristomial protoplasm; LA, lips of aperture; A, aperture; B, buccal cavity (infundibulum); C, cytopharynx; L, lorica wall; Mi, micronucleus; FV, food vacuole; Ma, macronucleus; Hk, haplokinety; Pk, polykinety; M, myonemes; S, supporting structure; K, kinety of unknown origin and function; H, hiatus, or gap in peristomial protoplasm; F, fold in lorica wall.

Method of Asexual Reproduction:

Asexual reproduction in this species, as in others of the genus, results in the production of a swarmer or telotroch larva (Fig. 11). It was a process of binary fission. A cleavage furrow formed at the left of the peristomial area of what was to be the parent or residual body (Fig. 10). The first intracellular organelle to divide was the micronucleus, followed by the buccal cavity. The actual division of the micronucleus was not observed, but the distad positions of the daughter micronuclei in later dividing forms indicated the path of early separation of the daughter micronuclei. The macronucleus was the last internal structure to divide; its division only slightly preceded complete cytoplasmic separation of the swarmer and residual body (Figs. 9, 10). Prior to its division the macronucleus became elongate and narrow, and took the form of the letter "W" (Fig. 9). The division sequence (Figs. 9–11) described here from fixed material differs only slightly from that given by Willis (1942) for *L. tattersalli*. The following observation was made on fresh hanging-drop preparations: After completely separating from the residual body, the new telotroch larva became very active and moved from wall to wall of the lorica. It pressed against the residual body and eventually escaped from the parent lorica through the hiatus in the peristomial cytoplasm (Fig. 6) of the residual body. After escaping, the larva remained active (swimming rapidly) on the surface of the lamella for several hours. I did not observe attachment of the larvae to the gills.

Evidence of Sexual Processes:

Ubisch (1913) described the formation of microgametes (microconjugants) and the process of conjugation for *Lagenophrys platei.*

Kane (1965) also reported conjugation of microconjugants with macroconjugants which were produced from an unequal division of the parent or residual body. Although no conjugation was observed in fresh specimens, evidence of sexuality was found in fresh and fixed, stained specimens of *L. callinectes.* Two bodies (5–15 μ long) which were apparently microconjugants were often found in a single lorica (Figs. 3, 4, 12). These bodies, at their largest, had a slightly anterior girdle of cilia, and were free within the lorica cavity. They were apparently produced by the division of a single original pro-microconjugant. Once, what appeared to be the fusion of a microconjugant and a macroconjugant was observed within a lorica (Fig. 12).

Behavior of the Ciliate

The most conspicuous behavioral characteristic of this species was its ability to open and close its lorica aperture by moving its anterior and posterior lip elements. This movement was observed many times in fresh hanging-drop preparations of gill material. It consisted of a gradual separation of the anterior and posterior lip elements to a distance equal to the greatest open diameter of the lorica aperture (Figs. 5, 14), followed by a rapid snapping together of these elements (Fig. 3, closure of the aperture). During the opening process portions of the buccal ciliature were extended through the aperture into the surrounding medium. These cilia were quickly withdrawn before closure of the aperture. Generally, this procedure reminded one of the rhythmic actions of the cirri of the feeding barnacle. The ciliate also could hold the aperture open and extrude its cilia into the surrounding medium for an indefinite period or retain the buccal ciliature within the lorica while the aperture was fully open. It is impossible to state which of these methods is more often used by the ciliate in its normal feeding. According to the kind or degree of stimulus, the ciliate may use all positions of the buccal ciliature for feeding.

Host-Commensal Relationship

The high degree of host-specificity of members of this genus has been pointed out by most authors working on the genus (see particularly Nenninger (1948) and Kane (1965)).

As described earlier, the lorica of *Lagenophrys callinectes* was closely attached to the gill surface of its host. There was no evidence that the ciliate gained any nourishment from the crab, or that it caused any direct injury to the host. In heavy infestations (Fig. 2), however, the ciliate's lorica and body conceivably could interfere partially with the normal diffusion of gases across the gill membrane. Experiments to test this point must yet be conducted. The only species of *Lagenophrys* reported as a possible ectoparasite was *L. orchestiae* found on a semi-terrestrial amphipod (*Orchestia cavimana*) by Abonyi (1928).

Observations of the regular moulting of the blue crab revealed that at each ecdysis (during summer) the total ciliate and gill fauna was shed or lost with the old gill cuticle. This process definitely limited the life-span of individuals of *Lagenophrys* or other host-dependent organisms on the cuticle or shell of the crab. The recently moulted (soft) crab was free of *Lagenophrys* and apparently had to become gradually reinfested during the calcification of its cuticle or thereafter. The older crabs which had undergone a final ecdysis would have no mechanism to free themselves of increasing numbers of branchial epizoonts.

The method of new infestation or reinfestation is not known for this species. Transfaunation experiments with aquarium-shed crabs (known to be uninfested) in the presence of infested crabs should prove informative.

Other crustaceans found in close association with the blue crab were examined for species of *Lagenophrys* from Chesapeake Bay, Maryland, and Chincoteague Bay, Virginia: mud crab, *Panopeus herbstii* (negative); mud crab, *Eurypanopeus depressus* (negative); spider crab, *Libinia emarginata* (negative); and grass shrimp, *Palaemonetes* sp. (positive).

The above hosts carried no *Lagenophrys* with the exception of the grass shrimp. A species of *Lagenophrys* distinct from *L. callinectes* was found on the body cuticle and carapace of this shrimp from Chincoteague Bay, Virginia. It differed from *L. callinectes* in the shape and size of its lip elements and in its lorica size. This species from the shrimp must be studied further to determine its specific identity. For the present it appears that *L. callinectes* is found only on the gills of the blue crab.

Comparison of *L. callinectes* with Other Congeneric Species

The characteristics used to separate species in this relatively large genus have been reviewed briefly by Corliss & Brough (1965) and in greater detail by Kane (1965). Morphological and morphometric characteristics of significance are reported to be the shape and size of the lorica, the form and number of the lip elements, and the form and size of the macronucleus. Kralik (1962) and Lom (personal communication) have questioned the validity of using the form and size of the loricae of loricate peritrichs as diagnostic characteristics. I have already pointed out the variation which occurs in the lengths of macronuclei in different developmental periods of this ciliate's life. With these points in mind, I have found the nature of the lips of the aperture, the size of the lorica, the form of the lorica (in lateral view), the pattern of the kineties (compared *L. callinectes* with *L. nassa* [by Lom, 1963, 1964[3]]) of the infundibular region, and host specificity to be the most useful distinguishing characteristics for *L. callinectes.* Corliss & Brough have pointed out that host specificity could, within limits, be considered as a specific characteristic, although Fenchel (1965) expressed doubt as to the long-term usefulness of this criterion. Much more work needs to be done in searching for possible use of more than one host species by a single species of *Lagenophrys.*

Lagenophrys callinectes was found to be most similar to *L. articularis* Nie & Ho, 1943 from the freshwater shrimp *Palaemon nipponensis,* and *L. lunatus* Imamura, 1940 from the marine and brackish-water shrimps *Leander paucidens* and *Palaemon varians.* Both of these species were described in Japan, however, and *L. callinectes* differs from each of these species and the other species of the genus in its distinct lip structure. The very short left anterior lip element (Fig. 5, dorsal view) of *L. callinectes* appears unique in the whole genus. It further differs from the two preceding species in lorica size, and from all known members of the genus in localities and host.

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CONCURRENT HAPLOSPORIDIAN INFECTIONS OF THE OYSTER, *CRASSOSTREA VIRGINICA* (GMELIN)

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Reprinted from THE JOURNAL OF PARASITOLOGY
Vol. 53, No. 2, April 1967, p. 248–253
Made in United States of America

THE JOURNAL OF PARASITOLOGY
Vol. 53, No. 2, April 1967, p. 248–253

CONCURRENT HAPLOSPORIDIAN INFECTIONS OF THE OYSTER, *CRASSOSTREA VIRGINICA* (GMELIN)

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ABSTRACT: The concurrent, natural infection of 6 of 101 oysters by the haplosporidians *Minchinia costalis* (Wood and Andrews, 1962) and *Minchinia nelsoni* Haskin, Stauber, and Mackin, 1966, is reported from Chincoteague Bay, Virginia. Sporocysts and spores of *M. costalis* (the more abundant species) occurred throughout the oyster's tissue, whereas those of *M. nelsoni* were restricted to the digestive diverticula. *M. costalis* was characterized by fixed sporocysts 13.6 μ in greatest dimension and unfixed spores measuring 4.3 by 3.3 μ, whereas fixed sporocysts of *M. nelsoni* were 37.7 μ in greatest dimension, and its unfixed spores measured 8.1 by 5.5 μ. The spore operculum and nucleus of *M. costalis* are morphologically distinct from those of *M. nelsoni*. It is suggested, however, that because of otherwise close morphological, host, and ecological similarities, the two species show greater affinity to one another than either does to other species of *Minchinia*.

Four species of *Minchinia* Labbé, 1896 (Haplosporida: Haplosporidiidae) have been described from North America: *M. pickfordae* (Barrow, 1961) Sprague, 1963, in freshwater snails *Lymnaea, Physa,* and *Heliosoma*; *M. costalis* (Wood and Andrews, 1962) Sprague, 1963, in the American oyster, *Crassostrea virginica*; *M. louisiana* Sprague, 1963, in the mud crab, *Panopeus herbstii*; and recently *M. nelsoni* Haskin, Stauber, and Mackin, 1966, also from the American oyster.

Herein is presented a description of mixed infections by two species of *Minchinia* in the same host individuals, and a further demonstration of their specific differences. The two species are *M. costalis* and *M. nelsoni* found in the American oyster from Delaware and Chesapeake bays and adjacent waters of the central eastern coast of the United States. Each of these species has been referred to by terse but vague abbreviations: *M. costalis* as "SSO" (seaside organism, Wood and Andrews, 1962); *M. nelsoni* as "MSX" (multinucleate sphere X, Mackin, 1961; Haskin, 1962; Andrews, Wood, and Hoese, 1962; Engle and Rosenfield, 1963) because, until recently, *M. nelsoni* had not been named or described (Haskin et al., 1966; Couch, Farley, and Rosenfield, 1966). These species have been indicted as pathogens of the oyster through histological and epizootiological studies by Haskin, 1962; Haskin, Canzonier, and Myhre, 1965; Andrews et al., 1962; Andrews, 1962, 1966; Farley, 1965b; Couch et al., 1966.

Of the two species *Minchinia costalis* appears to have a more restricted ecological distribution. It has been reported, to date, only from the high salinity waters (20 to 30 parts per thousand) of seaside Maryland and Virginia, from lower Chesapeake Bay (Andrews et al., 1962), and from Delaware Bay (Haskin et al., 1966). The spores of *M. costalis* occur throughout its known range, presenting an obvious, easily diagnosed stage (Wood and Andrews, 1962; Farley, 1965a) during its spore producing season of May through July (Wood and Andrews, 1962). *M. nelsoni*, however, is more widely distributed in coastal waters of the Middle Atlantic states. This species is able to exploit lower salinity, estuarine waters (waters above 15 ppt salinity). Spores of *M. nelsoni* have been found infrequently, though they have been reported in oysters from Manokin River and Tangier Sound in the Chesapeake Bay and from Chincoteague Bay, Maryland (Couch et al., 1966).

Evidence of overlap of ranges for the two species was first reported by Andrews et al. (1962). This overlap was in the waters of seaside Maryland and Virginia, and in lower Chesapeake Bay.

During June 1965 and June 1966, sporocysts and spores of both *Minchinia costalis* and *M. nelsoni* were found in oysters from one of the main areas of distributional overlap, Chincoteague Bay, Virginia.

MATERIALS AND METHODS

One hundred and one dead and dying oysters from groups of uninfected oysters which had been

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Received for publication 28 September 1966.

introduced into Chincoteague Bay at Franklin City, Virginia, prior to June 1964, were examined during May and June 1965, and June 1966, for the presence of *Minchinia costalis* and *M. nelsoni.* Thirty-seven of these oysters contained sporocysts and spores of *M. costalis,* whereas six others contained sporocysts and spores of *M. costalis* and *M. nelsoni.* One oyster contained only spores of *M. nelsoni.* Of the remaining 57 oysters, 31 were heavily infected with plasmodia and 26 were negative for haplosporidian parasites. Fresh sporocysts and spores of both species from the six oysters with mixed infections were studied as follows: measurements were made of 50 fresh, unfixed spores of *M. costalis* and 50 fresh, unfixed spores of *M. nelsoni.* Fresh squashes of digestive diverticula tissues from one of the six oysters were fixed in Davidson's fixative (Shaw and Battle, 1957) and stained with Heidenhain's iron-alum hematoxylin. One oyster was serially sectioned at 8 μ and stained with iron hematoxylin. In this stained material 25 mature sporocysts of each species were measured; counts of sporocysts of both species were made to determine their relative abundance; and the numbers of spores per sporocyst in 50 sporocysts of each species were counted. The diameters of 20 spore nuclei of each species were measured in the fixed and stained material. Photomicrographs of fresh and stained spores and sporocysts were made at the same magnification (970 ×). Detailed drawings were made of the spores of both species with the aid of the camera lucida. Measurements are in microns.

Comparison of *Minchinia costalis* and *M. nelsoni* in concurrent infection

The stages chosen for comparison were the sporocysts and spores of both species. The plasmodial or vegetative stages were abundant in each of the concurrent infections, but because of moribund conditions in the dead or dying oysters their differences were difficult to distinguish (differences used to distinguish plasmodia of the two species were: nuclear membranes of *Minchinia costalis* usually not as sharply defined or distinct as those of *M. nelsoni*; endosomes of *M. costalis* nuclei proportionately larger, less distinct, more diffuse, and more central than endosomes of *M. nelsoni*). A separation of the two species was based on their obvious morphological differences as well as different tissue preferences found for their late sporulative stages. Mature and immature sporocysts and spores of the two species were compared in order not to confuse immature stages of the larger species, *M. nelsoni,* with mature stages of *M. costalis.*

The sporulative stages of *Minchinia costalis* and *M. nelsoni* in concurrent infections showed no significant structural, morphometric, or developmental differences when compared to similar stages of each in separate, pure infections. It was not determined, in these concurrent infections, whether or not one species of parasite held a dominant role over the other in pathogenicity to the host.

RESULTS

Relative distribution and abundance of *Minchinia costalis* and *M. nelsoni* in the host

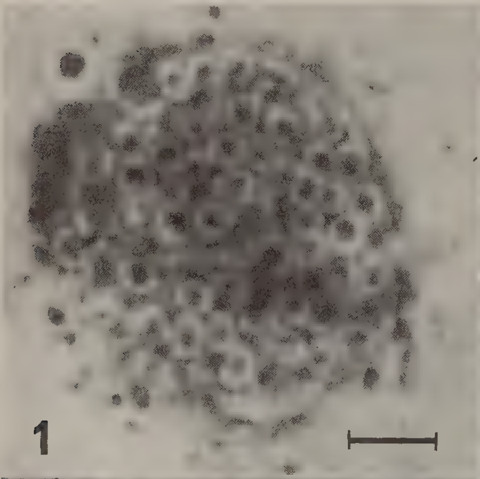
In the six oysters found infected with both species, the sporocysts and spores of *Minchinia costalis* occurred in squashes of gill, mantle, epithelium, and connective tissue. Sporocysts and spores of *M. nelsoni* were found only in squashes of tissue from the area of the digestive diverticula as was reported by Couch et al., 1966, for *M. nelsoni* from Chesapeake Bay. The ratio of sporocysts of *M. costalis* to sporocysts of *M. nelsoni* was approximately 7:1 in the region of the digestive diverticula, and associated connective tissue. Spores of *M. costalis* were free in the tissues in much greater numbers than those of *M. nelsoni.*

Plasmodia: Plasmodia of each species inhabited the same tissues of the oyster (connective, epithelia) in both concurrent and "pure" infection. Only the sporulative stages were partially segregated as described above.

The chief criteria for morphological maturity of sporocysts and spores for both species were: (1) contained spores possessed fully formed walls and opercula; (2) little cytoplasm, other than sporoplasm limited by spore walls, found within sporocyst membrane; and (3) majority of sporoplasms within spores stained darkly (Fig. 2) with iron hematoxylin. Sprague (1963) reported a similar intense staining for mature spores of *Minchinia louisiana.*

Sporocysts: The differences in size and form in fixed and stained material (Figs. 1, 2) were as obvious as in fresh material (Figs. 3, 4).

The greatest dimension of mature sporocysts ranged from 9 to 23 (mean, 13.6) in *Minchinia costalis* (Fig. 2) and 30 to 51 (mean, 37.7) in *M. nelsoni* (Fig. 1). Immature sporocysts of *M. nelsoni* (minimum greatest dimension, 30) were larger than the largest sporocysts of *M. costalis.* The total size range of 30 to 51 for *M. nelsoni* agreed closely with the range of 28 to 54 given by Couch et al. (1966) for this species in sectioned material from the Manokin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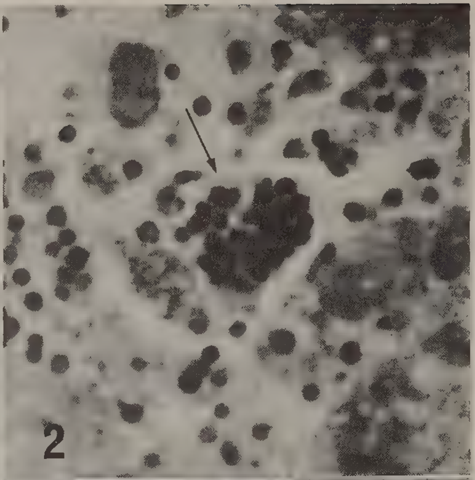
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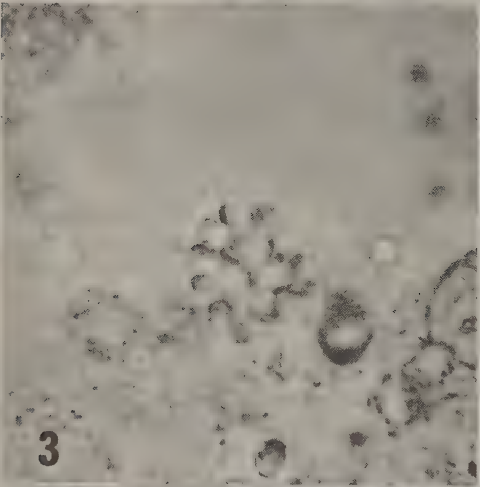
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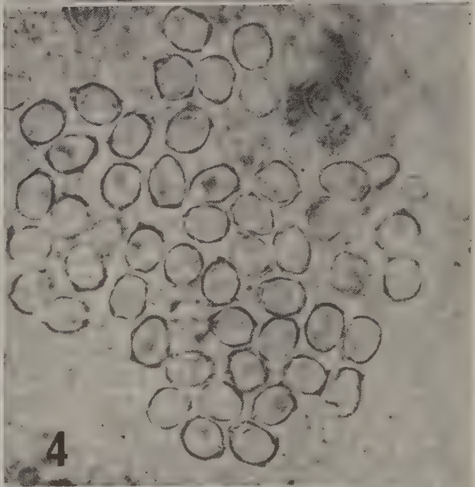
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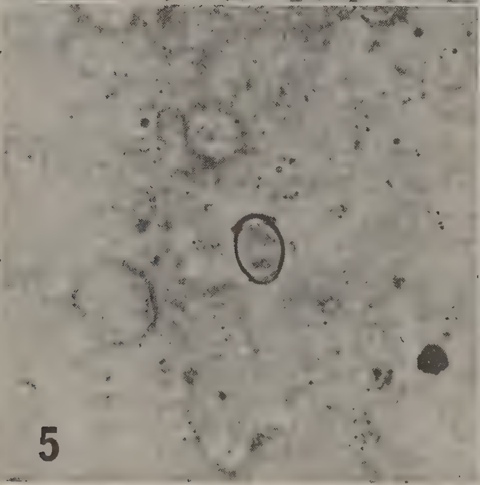
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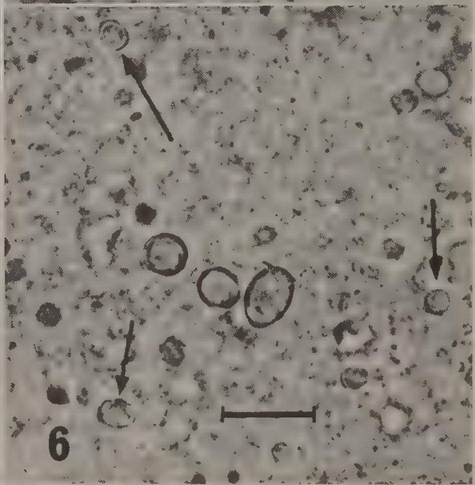
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TABLE I. *Mean size and range of sizes for fresh spores of two haplosporidians from the oyster,* Crassostrea virginica.

Species	Length		Width	
	Range	Mean	Range	Mean
M. costalis[1]	3.0– 5.5	4.3	2.9–4.6	3.3
M. nelsoni	6.8–11.4	8.1	4.6–6.8	5.5

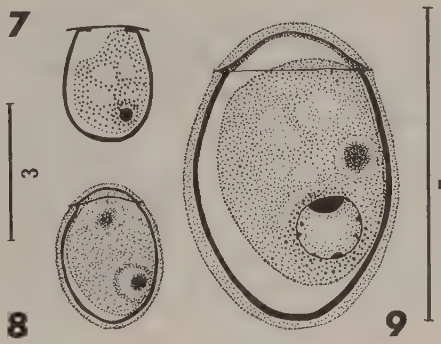
[1] Since these measurements were made for *Minchinia costalis* a few macrospores of this species have been found. The size of these spores overlap the minimum size reported here for *M. nelsoni*. These macrospores are rarely found in typical sporocysts of *M. costalis*, and appear thin-walled and are usually collapsed, indicating that they are anomalous stages.

River, Chesapeake Bay. In one of the concurrent infections sporocysts of *M. costalis* contained 8 to 51 spores (Fig. 3) and the sporocysts of *M. nelsoni* contained 10 to 70 spores (Fig. 4). Counts were made for the sporocysts which were clear and least distorted; for many sporocysts of both species accurate counts could not be made. Apparently the number of spores per sporocyst is not a reliable characteristic for distinguishing between the two species, because of the large variation in the number within each species and the great overlap of ranges.

Spores: Measurements (in microns) of fresh, unfixed spores of each species are presented in Table I.

The significant difference in size was obvious in squashes or smears containing free spores of both species (Fig. 6). The mean measurements for spores of *Minchinia costalis* are slightly larger than the 3.09 by 2.58 μ given by Wood and Andrews (1962) in their original description from fixed, stained sections. They reported, however, a 25% reduction in spore size after fixation, sectioning, and staining. The size range of spores of *M. nelsoni* agrees well with measurements given by Couch et al. (1966) for spores of this species from Manokin River, Chesapeake Bay (Fig. 5).

The diameter of the spore nucleus of *Minchinia costalis* ranged from 1.1 to 1.7 with an average diameter of 1.2, whereas the spore nucleus of *M. nelsoni* ranged from 1.5 to 2.8 with an average diameter of 2.0.



FIGURES 7–9. Drawings of optical sections of spores of *Minchinia costalis* and *M. nelsoni*. **7**. Spore of *M. costalis* (redrawn after Wood and Andrews, 1962). **8**. Spore of *M. costalis* from Chincoteague Bay, Virginia. **9**. Spore of *M. nelsoni* from Chincoteague Bay. Scales are in microns.

Several specific morphological characters of the two species were consistent and distinct. The spore of *Minchinia costalis* possessed a shallow operculum ($< 1\ \mu$) which upon first examination gave the spore a truncated appearance, as figured by Wood and Andrews (1962) (Fig. 7). Upon close examination of fresh and well-prepared fixed spores the true shallow convex nature of the operculum was seen (Fig. 8). The spore of *M. nelsoni* had a proportionately deeper and more obvious (convex) operculum ($\geqq 1\ \mu$) (Figs. 5, 6, 9). The nuclear membrane in spores of *M. costalis* was not as distinct as in spores of *M. nelsoni*, and the endosome of the former was central or eccentric and diffuse, whereas the endosome of *M. nelsoni* was peripheral and distinct (Figs. 8, 9). Other than the endosome, there was usually little basophilic material in the spore nucleus of *M. nelsoni*. Occasionally, small dark staining particles (Fig. 9) could be found around the inside periphery of the nuclear membrane. However, these particles could not be found in many nuclei. Spores of both spe-

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FIGURES 1–6. Sporocysts and spores of *Minchinia costalis* and *M. nelsoni* (970 ×). Each scale equals 10 μ. **1**. Sporocyst of *M. nelsoni* (iron hematoxylin). **2**. Sporocyst (arrow) of *M. costalis* from same squash as Figure 1. **3**. Fresh sporocyst of *M. costalis*. **4**. Fresh sporocyst of *M. nelsoni*. **5**. Fresh spore of *M. nelsoni* from Manokin River, Chesapeake Bay. **6**. Fresh spores of *M. costalis* (arrows) and *M. nelsoni* (center 3) in oyster digestive diverticula tissue from Chincoteague Bay, Virginia.

cies contained a small spherule in their sporoplasm. This inclusion was more difficult to find in spores of *M. costalis* than in those of *M. nelsoni*. The structure has been observed in spores of most species of *Minchinia* (Granata, 1914; Pixel-Goodrich, 1915; Sprague, 1963), and was easily observed in many spores of *M. nelsoni* (Fig. 9). The spherule may have been difficult to observe in spores of *M. costalis* because of their small size (smallest spore reported for the genus *Minchinia* by Wood and Andrews, 1962).

DISCUSSION

Minchinia costalis and *M. nelsoni* showed antigenic differences as demonstrated by Barrow and Taylor (1966) who tested sporocysts and spores of both species from the same concurrent infections reported in this paper. Differences in tissue preferences of sporulative stages and some differences in geographical distribution of the two species have been pointed out. The apparent infrequency of complete sporulation of *M. nelsoni* in the oyster has not been explained. This infrequency suggests a difference in the life histories of *M. nelsoni* and *M. costalis*. The latter species has a regular season (May through July) of spore production throughout its range.

Beyond these differences, the two species display similarities that suggest a close intrageneric relationship. Morphologically, the plasmodia of the two species are similar, with close examination of the nuclei being necessary for separation. The spores are generally similar in form, with size, form of operculum, and nuclear morphology being the best distinguishing characters. Their ecological ranges overlap in seaside areas, demonstrating a comparable, if not equal, ability to tolerate high salinities. They utilize the same host species, and their plasmodia, as previously mentioned, occupy similar tissue sites. The patterns of mortality attributed to both parasites occurred during the warm seasons of the year (summer and fall; see Andrews et al., 1962; Andrews, 1966). Although a lack of detailed data on these general similarities prevents a rigid interpretation, the similarities do suggest morphological and physiological affinity for the two species.

Comparisons of similarities between *Minchinia costalis* and *M. nelsoni* were made relative only to comparisons of these species with other congeneric species (see Couch et al., 1966, for listing of species of *Minchinia* and their hosts) and not relative to other genera, etc. All other species of *Minchinia* have been found in different hosts of generally unrelated taxa. None, to this author's knowledge, have been found in concurrent infections.

It is not uncommon to find two or even more congeneric species of certain parasites within the same host individual. For example, in the American oyster concurrent infections by spores of *Nematopsis ostrearum* Prytherch (1938) and *Nematopsis prytherchi* Sprague (1949) (Eugregarinina: Porosporidae) were found in locales where the ranges of their respective definitive hosts overlapped (Sprague, 1949). Though laboratory transmission of *Minchinia costalis* and *M. nelsoni* has not been achieved and the full life cycles of these two species are unknown, it is apparent that epizootiological, morphological, and serological data demonstrate differences in these two species as well as their concurrent presence in oysters from Chincoteague Bay, Virginia. However, other similarities suggest that *M. costalis* and *M. nelsoni* are more closely related to one another than either is to other species of *Minchinia*. It would be unjustified, on the basis of present knowledge, to suggest a more primitive or more specialized state of adaptation in the oyster for either species. Concerning "parasitic and partially asexual protozoans," Mayr (1963, p. 49) has stated: "The widespread occurrence of sibling species in these organisms is highly probable on the basis of much indirect evidence."

ACKNOWLEDGMENTS

I wish to thank Dr. John G. Mackin and Dr. Victor Sprague for reading the paper and offering helpful suggestions.

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Natural Hemagglutinins in Marine Fishes

BY KENNETH B. CUMMING[1]

Abstract

A large number of serological crossmatches between 33 species of marine fishes indicated that the blood of many of them contains natural agglutinins. These normal bloods are potential serological reagents for racial studies in fishery work. One example is presented to show the heterogeneity of haddock erythrocytes by using the serum of winter flounder as the differentiating agent.

Introduction

Investigations of the identification of races of fishes have assumed new importance with the advent of serological and biochemical methods of population analysis (Parrish, 1964; Cushing 1964). Several reports review the history (Ridgway and Klontz, 1960), indicate the genetic significance (Sanders and Wright, 1962), and show the application (Sindermann, 1961) of serological techniques in fishery research.

Several techniques are known for distinguishing the red blood cells of one fish from those of another. Recently emphasis has been on techniques that use antisera obtained from closely related or even the same species of fish (Ridgway, 1962). This paper demonstrates the existence of many naturally occurring hemagglutinins in marine fishes which could serve as potential antisera for blood typing. As an example, the sera from winter flounder are used to indicate agglutination patterns in the red blood cells of haddock.

Methods

Fish were obtained from net hauls of the *Albatross IV* in the Gulf of Maine and by angling near Woods Hole.

Whole blood was taken from the heart with disposable syringes (5 and 10 ml). When red blood cells alone were required, a 1-% aqueous solution of the disodium salt of ethylene diamine tetraacetic acid (EDTA) (1 mg/ml of whole blood) was put in the syringe as an anticoagulant. The red cells were centrifuged down, washed three times with 1-% saline, diluted to a 10-% suspension, and then kept in a refrigerator at 4°C. Serum was extracted from blood samples that were taken without anticoagulant, and was frozen in storage vials at –20°C. Cells were not held longer than 1 week, and were usually tested within 2 days. Serum samples, on the other hand, were thawed as needed and refrozen.

Tests for agglutination were made by mixing a drop of suspended red cells with a drop of serum in one chamber of a disposable plastic agglutination tray which contains 96 chambers of a 2.5-ml capacity each. The trays were agitated by hand for 30 min at room temperature and then scored on the basis of degree of agglutination. The scores are expressed as: — (negative); + (a fine, sand-grain appearance); 1+, 2+, 3+, and 4+ (a single clump of cells surrounded by clear serum).

Absorptions were performed by mixing equal volumes of undiluted serum and packed cells in a small centrifuge tube and letting the tube stand for 30 min at room temperature. After separation from the cells by centrifugation, the absorbed serum was decanted and tested for completeness of absorption by mixing a drop of the serum with a drop of cell suspension. One absorption was usually sufficient to remove all the agglutinins which were specific for the absorbing cells. Some hemolysis was seen in most absorptions leaving the supernatant fluid redder than the usual straw color, but subsequent agglutinations were still readily visible in the test chambers.

Natural Fish Hemagglutinins

The general pattern of agglutinations for many of the crossmatches between 33 fish species, arranged according to the phyletic order of the American Fisheries Society (Bailey *et al.*, 1960), is presented in Table 1. All of the crossmatches

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REPRINTED FROM INTERNATIONAL COMMISSION FOR THE NORTHWEST ATLANTIC FISHERIES
RESEARCH BULLETIN NUMBER 4, 1967

TABLE 1. Scoring for natural agglutinins in 33 species of marine fish. The scores contain three numbers per block of crossmatches: upper left — number of positive responses, upper right — sum of agglutination scores, and lower centre — number of crossmatches. A zero in place of the upper two numbers indicates no positive responses. Blanks indicate blocks in which no tests were made. The subscripts indicate that cells (c), sera (s), or both (b) may be differentiated by the given crossmatch.

	Sera														
Cells	*Squalus acanthias* (spiny dogfish) 1	*Raja ocellata* (winter skate) 2	*Raja radiata* (thorny skate) 3	*Dasyatis centroura* (roughtail stingray) 4	*Brosme brosme* (cusk) 7	*Gadus morhua* (Atlantic cod) 8	*Melanogrammus aeglefinus* (haddock) 9	*Merluccius bilinearis* (silver hake) 10	*Pollachius virens* (pollock) 11	*Urophycis chuss* (squirrel hake) 12	*Centropristes striatus* (black sea bass) 13	*Roccus saxatilis* (striped bass) 14	*Pomatomus saltatrix* (bluefish) 15	*Stenotomus chrysops* (scup) 17	*Tautoga onitis* (tautog) 18
1. *Squalus acanthias* (spiny dogfish)	0 25		9/9 25		0 25	0 25	0 25	0 25	0 25		1/1 25	0 25	0 25	0 25	
4. *Dasyatis centroura* (roughtail stingray)				1/1 4											
5. *Alosa sapidissima* (American shad)						4/9 5_s	5/19 5		2/8 5_s		0 5	0 5	1/1 5	0 5	2/2 5
6. *Clupea harengus* (Atlantic herring)	0 10	0 25	0 25	0 25	0 10	7/4 25	2/1 25		0 25		0 25	0 25	0 25	0 25	14/16 25
7. *Brosme brosme* (cusk)	1/1 10				0 10	0 5	0 5		0 5		1/1 5	4/3 5	0 5	0 5	0 5
8. *Gadus morhua* (Atlantic cod)	7/9 25	0 25	4/9 25	0 20	8/20 25_b	0 25	0 25	19/59 25_b	6/13 25_s		0 25	6/7 25	8/8 25	3/3 25	4/4 25
9. *Melanogrammus aeglefinus* (haddock)	0 25	0 25	0 25	0 25	0 25	0 25	0 25	0 25	0 50		12/43 37	0 37	0 25	2/3 50	0 25
10. *Merluccius bilinearis* (silver hake)						0 25	3/5 50	0 25	0 21	0 25	5/20 5			4/3 5	
11. *Pollachius virens* (pollock)	0 25	0 25	10/7 25	0 20	0 25	0 25	0 25		0 25		0 25	5/5 25	0 20	0 25	4/5 25
12. *Urophycis chuss* (squirrel hake)	9/7 25				0 25	0 45	0 45	0 20	0 45			0 25		0 25	
13. *Centropristes striatus* (black sea bass)						0 25	0 25	5/5 25			0 25	19/53 25	2/2 25	0 25	15/58 25_s
14. *Roccus saxatilis* (striped bass)	4/2 25	0 25	0 25	0 20	0 25	0 40	2/1 40	15/13 40	0 25		15/60 15	0 25	10/5 25	5/4 38	6/18 34_s
15. *Pomatomus saltatrix* (bluefish)	20/12 25	10/17 15	0 25	0 20	0 20	0 25	4/2 25	0 25	0 25		0 25	18/41 25_s	3/3 25	10/6 25	25/38 25
16. *Selar crumenophthalmus* (bigeye scad)	10/9 25	20/64 25_s	0 25	3/2 20	10/9 25	0 25	10/10 25		0 25		23/52 25_s	0 25	5/4 25	0 25	7/5 25
17. *Stenotomus chrysops* (scup)	17/9 25	5/8 20_s	5/4 25	0 20	0 25	54/80 125_s	0 25	0 25	0 25		25/99 25	10/40 25_s	5/3 25	0 50	11/36 25_s
18. *Tautoga onitis* (tautog)	0 25	0 15	0 25	0 20	0 25	0 25	0 25	0 25	0 25		25/49 25	2/5 25	13/8 25	0 25	0 25
19. *Sarda sarda* (Atlantic bonito)	5/4 25	13/27 50_s	0 25	7/6 30	6/4 50	0 25	0 25	5/5 25	11/7 25	0 20		0 25		17/13 48	
20. *Scomber scombrus* (Atlantic mackerel)	4/3 20	15/14 15	0 25	7/4 20	0 25	0 25	0 25	0 20	0 25		0 25	2/1 25	1/1 25	0 25	16/21 25_s
21. *Scomberomorus cavalla* (king mackerel)	3/3 10	6/9 6	2/1 10	8/13 12	2/4 30	0 10	0 10	0 10	2/2 10	0 8		0 10		0 10	
23. *Prionotus evolans* (striped searobin)	20/26 25	6/3 20	1/1 25	10/8 20	0 25	0 25	0 25	0 25	0 25		0 25	25/82 25	24/39 25_s	0 25	25/100 25
24. *Myoxocephalus octodecemspinosus* (longhorn sculpin)	0 25					0 25	5/5 41	6/6 25	10/15 16	5/5 25		3/3 25		0 20	
26. *Macrozoarces americanus* (ocean pout)	0 25					0 25	0 25	0 25				0 25		0 25	
27. *Paralichthys dentatus* (summer flounder)															
29. *Hippoglossoides platessoides* (American plaice)						0 15	0 15		0 15						
30. *Limanda ferruginea* (yellowtail flounder)															
31. *Pseudopleuronectes americanus* (winter flounder)	0 25	15/10 45	31/55 50_b	5/20 20_s	0 25	17/15 110	0 25	0 25	0 25		0 25	5/3 25	4/5 25	15/12 25	8/14 25
32. *Alutera schoepfi* (orange filefish)	18/23 25_s	5/10 15	8/5 25	15/43 20_s	5/3 25	0 25	0 25	0 25	0 25	0 20		0 25		6/3 25	
33. *Lophius americanus* (goosefish)	3/2 20	10/22 15_c	2/1 16	0 15	0 20	7/20 15_c	0 15		0 15		0 5	5/9 5	0 5	3/2 5	5/11 5

TABLE 1. (continued)

Sera															
Sarda sarda (Atlantic bonito) 19	*Scomber scombrus* (Atlantic mackerel) 20	*Scomberomorus cavalla* (king mackerel) 21	*Sebastes marinus* (redfish) 22	*Prionotus evolans* (striped searobin) 23	*Myoxocephalus octodecemspinosus* (longhorn sculpin) 24	*Anarhichas lupus* (Atlantic wolffish) 25	*Macrozoarces americanus* (ocean pout) 26	*Paralichthys dentatus* (summer flounder) 27	*Glyptocephalus cynoglossus* (witch flounder) 28	*Hippoglossoides platessoides* (American plaice) 29	*Limanda ferruginea* (yellowtail flounder) 30	*Pseudopleuronectes americanus* (winter flounder) 31	*Alutera schoepfi* (orange filefish) 32	*Lophius americanus* (goosefish) 33	Cells
0 25	0 25	0 10		0 25	1/2 25	3/5 25	4/3 25			3/4 25	0 15	3/2 25	25/100 25	0 25	1. *Squalus acanthias* (spiny dogfish)
8/21 10_s		2/8 4_s													4. *Dasyatis centroura* (roughtail stingray)
0 5		0 3		0 5	0 5		0 5	0 3		0 5	2/7 5_s	0 5		0 5	5. *Alosa sapidissima* (American shad)
0 25		0 10			0 34	0 10	0 30	0 25		0 25	0 25	0 25	3/3 25	0 26	6. *Clupea harengus* (Atlantic herring)
0 5		0 3		0 10	0 10	0 10	2/3 10	0 3		0 5	0 5	0 5	✓	0 10	7. *Brosme brosme* (cusk)
0 25	4/14 25_b	0 10	12/22 25_b	9/13 20	0 20	5/12 25_s	17/35 25	2/5 25_b	20/54 25	11/7 25_c	6/17 25_s	9/5 25	14/24 25_b	1/1 25	8. *Gadus morhua* (Atlantic cod)
0 25	0 15	0 10	10/23 25_s	0 20	0 25	5/20 25_s	0 25	0 25	0 25	0 20	10/40 25_s	14/23 25_b	0 25	0 10	9. *Melanogrammus aeglefinus* (haddock)
					15/42 25_c		3/2 5					15/55 25_s		5/20 10_s	10. *Merluccius bilinearis* (silver hake)
0 25	0 20	0 10	8/6 24	0 20	5/3 20	4/8 25	17/39 25	5/3 25	17/40 25_c	9/6 25	10/34 25_s	0 25	13/11 25	0 25	11. *Pollachius virens* (pollock)
			19/69 25_b		0 25					0 25		5/6 25		1/1 20	12. *Urophycis chuss* (squirrel hake)
					0 25		13/17 25_s					25/77 25		0 10	13. *Centropristes striatus* (black sea bass)
0 25	0 25	0 10		0 25	0 40	0 25	0 40	12/8 25		0 25	0 25	9/14 40_s	0 25	0 28	14. *Roccus saxatilis* (striped bass)
0 25	5/5 25	0 10		8/4 25	0 25	0 25	0 25	0 15		0 25	0 15	17/51 25_s	24/25 25	0 25	15. *Pomatomus saltatrix* (bluefish)
23/68 25_s		0 10	0 25	5/3 15	0 25	4/3 20	5/3 25	0 25		0 25	0 25	6/6 25	14/45 25_s	25/100 25	16. *Selar crumenophthalmus* (bigeye scad)
1/1 25	0 25	0 10	0 20	0 25	8/10 25	0 25	22/70 25_b	5/3 25	2/2 15	0 25	13/30 25_s	63/100 125_b	20/20 25	0 35	17. *Stenotomus chrysops* (scup)
2/1 25	0 25	0 10		0 25	0 25	0 25	0 25			0 20	0 15	0 25	5/5 25	0 35	18. *Tautoga onitis* (tautog)
0 95		0 10	6/3 25	0 15	5/3 25	0 25	6/14 25_s	4/3 25		0 25	0 15	5/3 25		0 40	19. *Sarda sarda* (Atlantic bonito)
0 25	4/4 25	0 10	0 25	0 25	0 25	0 25	0 25			0 25	0 15	13/15 50_c	15/23 25_b	11/25 25_s	20. *Scomber scombrus* (Atlantic mackerel
0 10	3/2 10	0 4		0 6	0 8	0 10	0 10	2/2 10		0 10	1/1 6	0 10		2/8 10_s	21. *Scomberomorus cavalla* (king mackerel)
5/5 15	15/26 25	10/23 10		0 20	0 25	3/2 20	6/4 25	3/3 25		0 25	11/11 25	5/4 25	6/4 25	0 25	23. *Prionotus evolans* (striped searobin
					0 25			0 25		0 25		18/36 25_c		4/13 35_b	24. *Myoxocephalus octodecemspinosus* (longhorn sculpin)
					0 25		0 25			2/1 25	0 20	10/17 25_s		0 25	26. *Macrozoarces americanus* (ocean pout)
								0 25	0 15	0 25	0 25	6/9 25_b			27. *Paralichthys dentatus* (summer flounder)
0 20	0 20	0 8						0 20	4/2 16	0 20	0 20	0 20			29. *Hippoglossoides platessoides* (American plaice)
							2/3 16	1/1 25	0 25	0 25	0 10	0 25			30. *Limanda ferruginea* (yellowtail flounder)
6/4 25	16/61 85_b		0 20	0 25	0 25	0 25	0 25	0 25		0 25	0 25	0 144	0 25	0 25	31. *Pseudopleuronectes americanus* (winter flounder)
6/9 25	0 10	4/4 10		0 15	0 15	0 25	22/23 25	0 25		0 25	0 15	0 25	0 25	0 25	32. *Alutera schoepfi* (orange filefish)
0 5		1/1 3			0 10		3/3 10	0 9		0 15	0 15	2/3 15	0 15	0 10	33. *Lophius americanus* (goosefish)

TABLE 2. Examples of agglutination patterns for the cells of Atlantic mackerel and Atlantic cod with sera of other species.

		Sera																								
		Bonito					American plaice					Witch flounder					Wolffish					Redfish				
	Samples	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	1	—	—	—	—	—	+	+	—	—	+	4+	4+	2+	4+	4+	—	2+	—	—	—	4+	—	+	3+	—
Atlantic	2	—	—	—	—	—	+	+	+	—	2+	4+	4+	2+	4+	4+	—	2+	—	—	—	4+	1+	+	3+	—
cod	3	—	—	—	—	—	—	—	—	—	—	2+	1+	—	1+	1+	—	4+	—	—	—	—	4+	+	—	—
cells	4	—	—	—	—	—	+	+	—	—	—	2+	3+	1+	3+	2+	—	2+	—	—	—	—	—	+	—	—
	5	—	—	—	—	—	+	+	—	—	—	2+	—	—	—	—	—	2+	—	—	—	—	—	+	+	—

		Sera																								
		American plaice					Winter skate					Winter flounder					Goosefish					Orange filefish				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	1	—	—	—	—	—	1+	1+	+	no	sera	1+	1+	+	1+	1+	—	—	—	+	4+	4+	1+	4+	—	—
Atlantic	2	—	—	—	—	—	1+	1+	1+	"	"	—	—	—	—	—	—	—	—	1+	4+	1+	—	1+	—	—
mackerel	3	—	—	—	—	—	1+	1+	+	"	"	4+	1+	+	1+	1+	—	—	—	1+	4+	—	—	+	+	—
cells	4	—	—	—	—	—	1+	1+	1+	"	"	1+	1+	+	—	—	—	—	—	1+	4+	1+	4+	2+	1+	1+
	5	—	—	—	—	—	1+	1+	1+	"	"	—	—	—	—	—	—	+	—	1+	4+	+	+	1+	—	—

of the cells of one species against the sera of a second species is here termed a "block." The 570 blocks tested included about 13,000 individual crossmatches. The average agglutination reaction was 2+ or stronger in at least half of the crossmatches in 29 of the blocks. In five blocks all crosses reacted 4+. The sera of black sea bass (13) and winter flounder (31) stand out as active agglutinators. A few of the strong reactions tested were active at a saline dilution of 1:16; most had titers of 1:4 or 1:8.

Seven blocks of Table 1 differentiate between the cells of individuals, 39 blocks differentiate between the sera and 15 blocks differentiate both. Even though the differentiation between sera of individuals by the use of fish cells has not been extensively applied in fishery work, this technique holds promise. Once the antigens of erythrocytes of some species are known, they can be employed (just as human cell types have been) to identify agglutinins in fish sera (Cushing, 1952; Suzuki and Morio, 1960).

Studies in which fish heteroagglutinins were used have been reported in several previous papers. Heteroagglutinins were demonstrated in marine fish by Noguchi (1903) and in freshwater fish by Toth (1932). Cushing and Durall (1957) crossed the cells and sera of channel catfish, *Ictalurus p. punctatus*, with brown bullhead, *Ictalurus n. nebulosus;* they reported that serum samples of individual channel catfish differentiated cells of brown bullheads. Brown bullhead serum reacted strongly with cells of sockeye salmon, *Oncorhynchus nerka*, but was not useful in differentiating fish from different areas (Ridgway, Cushing, and Durall, 1958). Natural hemagglutinins in the sera of kurokajiki, *Eumakaira nigra*, and shirokajiki, *Marlina marlina*, differentiate cells of bigeye tuna, *Parathunnus mebachi*, and cells of yellowfin tuna, *Neothunnus macropters*, (Suzuki and Morio, 1960; Suzuki, 1961, 1962). Finally, Sindermann and Honey (1964) showed that sera of winter skate, *Raja ocellata*, can differentiate cells of Atlantic herring, *Clupea harengus.*

Roughtail stingray (species 4 in Table 1), blue fish (15), and Atlantic mackerel (20), have natural isoagglutinins which react only when undiluted. Natural isoagglutinins have been found previously in eight species (Suyehiro, 1949; Cushing, 1956; Cushing, and Durall, 1957; Sindermann, and Mairs, 1961; Suzuki, 1961; and Sindermann, and Honey, 1964). They have been used only in catfish, spiny dogfish, and winter skate for blood group analysis where the titer permitted further work (Cushing and Durall, 1957; Sindermann and Mairs, 1961; Sindermann and Honey, 1964).

Species interactions tend to be less within a family than between families. Interactions were few within the cod, mackerel, and flounder families, but were numerous and strong among the several families represented by species 13–18 in Table 1.

Specific examples of the reactions for differentiating cells or sera or both are given in Table 2. Cells of Atlantic mackerel and Atlantic cod (five samples each) were crossed with the sera of the designated species. The sera of Atlantic bonito and American plaice did not react with the cells of Atlantic cod and Atlantic mackerel, respectively. Therefore, an insufficient titer or even absence of specific agglutinins make these sera unsatisfactory for differentiating between samples of the cells tested.

Sera of American plaice and winter skate contain agglutinins for Atlantic cod and Atlantic mackerel cells, repectively. Because of the weakness of reaction, there is doubt that the difference between a negative and weak positive reaction is significant. On the other hand, no question exists about the difference between a 4+ and a negative reaction. For this reason, a differential reaction is arbitrarily defined as a group of tests which show at least one 4+ reaction and one negative reaction in a row or column. With this definition in mind, the sera of some species such as witch flounder and winter flounder can be said to differentiate between cell samples of Atlantic cod and Atlantic mackerel, respectively. Similarly, the cell samples of Atlantic cod and Atlantic mackerel can be used to differentiate between serum samples of Atlantic wolffish and goosefish, respectively. Finally, both the cell and serum samples in some crossmatches of species can be used to differentiate each other as in Atlantic cod cells and redfish sera or Atlantic mackerel cells and orange filefish sera. In the few cases in which every crossmatch in the block reacted 4+, no tests were made to see if a differential reaction occurred after dilution of the sera.

Haddock Erythrocyte Antigens Detected by Fish Agglutinins

From the data in Table 1, winter flounder serum was selected as a promising source of reagent for differentiating individual haddock. Samples of red cells from 16 haddock caught near Chatham, Massachusetts, were tested against the pooled serum of several winter flounder from Great Harbor, Woods Hole. The cells of all haddock tested clumped positively and strongly. Next, the pooled serum was absorbed with the cells from individual haddock and then tested for remaining agglutinins (Table 3). The 11 distinct patterns of cell agglutination that occurred demonstrated the heterogeneity of haddock erythrocytes. Similar results were recorded by Suzuki and Morio (1960) when they absorbed the serum of one kurokajiki with the cells from five individual bigeye tuna, and by Suzuki (1961) when he absorbed the sera of two kurokajiki with cells from seven individual yellowfin tuna.

TABLE 3. Results of absorbing pooled winter flounder serum with erythrocytes of 16 individual haddock.

		Pooled winter flounder serum absorbed with haddock cells																
	Samples	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Pattern of agglutination
	1	—	—	3+	—	2+	—	—	—	—	—	—	3+	—	—	—	+	1
	2	—	—	3+	—	—	—	—	—	—	—	—	4+	—	—	—	—	2
	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
	4	—	—	1+	—	—	—	—	—	—	—	—	2+	—	—	—	—	2
	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
	6	—	—	2+	—	—	—	—	—	—	—	—	—	—	—	—	—	4
Haddock	7	—	—	2+	—	—	—	—	—	—	—	—	2+	—	—	—	—	2
cells	8	—	—	2+	—	2+	—	2+	—	—	—	—	2+	—	—	—	—	5
	9	—	—	2+	3+	2+	—	2+	—	—	—	—	—	—	—	—	—	6
	10	—	—	3+	—	—	—	2+	—	—	—	—	—	—	—	—	—	7
	11	—	—	3+	2+	3+	—	3+	—	—	—	—	—	—	—	—	—	6
	12	—	—	—	—	2+	—	2+	—	—	—	—	—	—	—	—	—	8
	13	—	—	1+	—	—	—	—	—	—	—	—	2+	—	—	—	—	2
	14	—	—	3+	—	—	—	3+	1+	—	—	—	3+	—	—	—	—	9
	15	—	—	4+	—	—	—	2+	—	—	—	—	4+	—	—	—	—	10
	16	—	—	3+	—	2+	—	2+	—	—	—	—	—	—	—	—	—	11

No further testing was done with pooled serum because the concentration of agglutinins decreased with time. Whereas freshly pooled serum of winter flounder gave a titer of 1:8, the titer decreased daily until even the undiluted serum did not react with haddock cells on the fourth day. Ridgway (personal communication) suggested that soluble isoagglutinogens may have neutralized the agglutinins. Another explanation may be that proteolytic enzymes caused the decrease in titer.

Even though the sera from several individuals may not be pooled, an alternative way of obtaining a large volume of blood is to bleed the same fish repeatedly. As much as 37 ml of whole blood (15.6 ml sera) have been obtained by intra-cardiac punctures from one adult scup in 4 weeks by bleeding about 1 ml per day. One drop of sera occupies approximately .02 ml; thus, as many as 50 tests per ml could be made. Agglutination tests have been made in capillary tubes for other experiments associated with this work with as reliable results as the tray method, yet requiring only one fourth the volume of sera.

Fifteen ml of whole blood have been obtained from one winter flounder in 3 weeks by bleeding 2½ml every 4 days and 15 ml from one striped bass in 2½ weeks by bleeding 3 ml every 4 days. No experiments were conducted to follow any titer level in these fish that were bled repeatedly.

Potential Value of the Natural Agglutinins of Fish

The present results can not be used to reflect any phyletic relationship because of the large number of unique blood systems that probably are involved. The indication of decreased agglutination within families suggests that a search for natural antisera would be best made between remote families. These reactions, however, may be associated more with genus or family specificity than with intraspecific differences.

The results of heteroagglutination indicate more agglutination variability in the serum of a species than in the cells. Toth (1932) made a similar observation in crossing *Rhodeus* cells with *Cyprinus* sera.

Pooling the sera of several individuals should be avoided at present but may be done later when sera from compatible individuals are found. However, individuals of a given species that are moderately large (1/2 kg or larger) could be used as live donors.

The titers of the natural fish agglutinins discovered in this study are not high. Isoimmunization experiments, however, have been successfully performed previously (Hildemann, 1956; Ridgway, 1962), and in other phases of this study (unpublished results) to produce a high titer of isoantibody. This technique may lead to wider use of isoagglutinins for racial separation.

Summary

1) Many hetero-hemagglutinins and a few iso-hemagglutinins were found to exist naturally in the blood of 33 species of fish.
2) There is no apparent relation between frequency or pattern of agglutination and phyletic order, although positive responses tend to be fewer within families than between families.
3) The titer of most agglutinations indicated activity only at the undiluted level, but some were still active at a saline dilution of 1:16.
4) Intraspecific variation in haddock erythrocytes was shown by the use of absorbed serum of winter flounder.
5) The normal sera of marine fish contain many agglutinins and may be valuable sources of blood-typing reagents.

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Comparative Study of Fowl Plague Virus and a Virus Isolated from Man

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FOWL PLAGUE is caused by an infectious filtrable virus and is characterized by high mortality among chickens. Although the disease has not occurred in the United States since 1929, it has been considered enzootic chiefly in eastern Europe, the Mediterranean basin, Egypt, and Asia. The disease has often been confused with that caused by the virulent form of Newcastle disease virus.

In 1959, slightly more than a month after he returned from a 2-month trip abroad, a 46-year-old white man with clinically diagnosed infectious hepatitis was hospitalized. He had been generally healthy during visits to Japan, Thailand, Ceylon, Egypt, Israel, Greece, Yugoslavia, Italy, Switzerland, and Spain. After his return, he complained of lassitude, headaches, and occasional chills during the first 2 weeks and bloating and indigestion during the next 2 weeks. On the 31st day he had a slight fever, and on the following day he was noticeably bloated and had indigestion, dark urine, constipation, and loss of appetite. Four days later his sclera showed a yellowish tinge. At this time, his physician clinically diagnosed his illness as infectious hepatitis and sent him to the hospital. Blood samples were collected the following day.

Initial studies were conducted at the National Communicable Disease Center, Public Health Service, Atlanta, Ga. These studies included inoculation of developing chicken embryos with blood clot material from the patient. This material was lethal for the embryos, and chickens inoculated with allantoic fluid from the embryos had clinical signs which resembled those of fowl plague. The results of these preliminary inoculations, and the fact that the patient had visited Egypt where fowl plague had been reported in 1959 (*1*), prompted the decision to submit the material to the Plum Island Animal Disease Laboratory for further study.

Material and Methods

Viruses. Blood from the patient was inoculated into primary rhesus monkey kidney tissue culture, HeLa tissue culture, suckling mice, 2-week-old mice, and developing chicken embryos.

Texas GB strain of Newcastle disease virus, the Brescia strain of fowl plague virus, and "N" virus (a fowl plague isolate) were used in serologic or challenge inoculation tests.

Diluents. Tryptose phosphate broth (Difco), physiological saline solution, and Alsever's solution (*2*) were used as diluents.

Animals. The monkeys (cynomolgus) were approximately 1 year old. The chickens, White

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Leghorns obtained from a breeding flock, were 6 to 12 months old. The ducklings (Pekin) were 2 to 3 weeks old. The developing chicken embryos were from a flock of White Leghorns. The chickens had not been vaccinated against Newcastle disease or exposed to infection with Newcastle disease virus.

Challenge inoculation. The chickens were inoculated intramuscularly with 1.0 ml. of Brescia strain of fowl plague virus containing 10^5 chicken lethal doses.

Virus neutralization. Lyophilized serums of chickens immunized against Newcastle disease virus and Brescia and Alexandrien strains of fowl plague virus and "N" virus were reconstituted with distilled water. The serums had been prepared at the Plum Island Animal Disease Laboratory in 1957. Fowl plague-like virus was diluted from 10^{-1} to 10^{-9} in tryptose phosphate broth, and 0.5 ml. of each virus dilution was added to a 0.5 ml. volume of reconstituted antiserum. The serum-virus mixtures were held for 30 minutes at room temperature, and then 0.1 ml. quantities of the mixtures were injected into the allantoic cavity of 10-day-old developing chicken embryos. Controls included diluent and normal chicken serum inactivated at 56° C.

Hemagglutination-inhibition. Hemagglutination-inhibition tests were conducted using fowl plague-like virus versus anti-fowl-plague serum (Brescia) and Brescia fowl plague virus versus fowl plague-like acute-phase and convalescent-phase serum samples from the patient. In these tests, virus dilutions of 1:640 were prepared in saline, serums were diluted 1:5, and 0.5 percent washed rooster red blood cells were prepared in Alsever's solution. Each tube contained 0.25 ml. each of diluted serum, virus dilution, and rooster red blood cell suspension. Hemagglutination controls employing inactivated normal chicken serum were included. The preparations were incubated 2 hours at room temperature.

Results

On first passage of blood clot material, one of five developing chicken embryos died 48 hours after inoculation. Guinea pig and chicken erythrocytes were agglutinated with suspensions of allantoic fluid from the embryo. In subsequent passages all the embryos died following inoculation, and allantoic fluid from the developing chicken embryos was infectious for chickens.

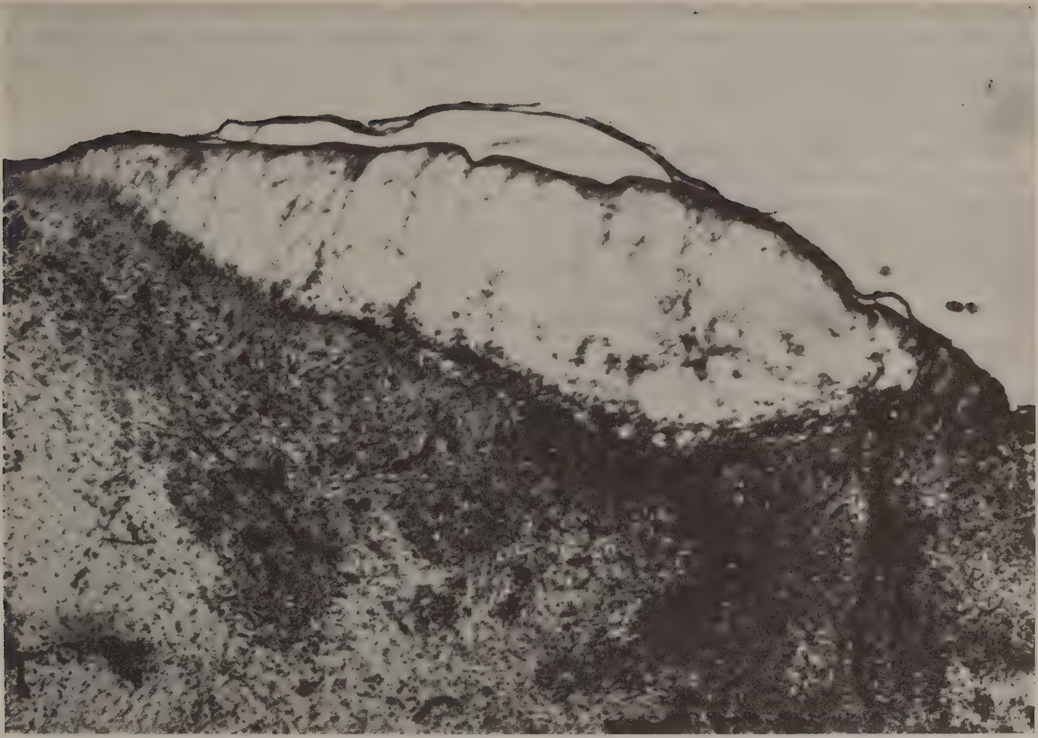
Ether treatment of the egg material containing infected allantoic fluid reduced infectivity from 10^{-6} to 10^{-3}. Attempts to pass the agent in primary monkey kidney tissue culture, suckling mice, and weanling hamsters were unsuccessful. The infected allantoic fluid was re-isolated in eggs from the original blood clot about 6 months after the first isolation.

Eighty-four embryos, inoculated with allantoic fluid of the second passage in developing chicken embryos, died within 48 hours.

Infection in chickens. Nine chickens were inoculated with allantoic fluid from the second passage in developing chicken embryos. Five birds were inoculated intramuscularly with 0.5 ml., two birds were inoculated with 0.5 ml. both intramuscularly and intravenously, and each of two birds received 0.5 ml. intravenously. All four birds inoculated intravenously were dead or moribund at 6 days postinoculation. Only one of five birds inoculated intramuscularly died.

Moderate signs of infection were observed in the survivors, which were reinfected with fowl plague-like virus passaged from embryo to chicken to embryo. Eight chickens were inoculated with fowl plague-like virus passaged once in embryo and once in chickens. Eight chickens were inoculated with 0.5 ml. of spleen suspension, two intramuscularly and six intravenously. Signs of infection developed in both birds inoculated intramuscularly, but one recovered. Signs of infection were seen in all six birds inoculated intravenously, and all died within 7 days postinoculation. The same inoculum tested for viability after storage for 8 months at −30° C. was found to be infective—four of seven chickens inoculated intravenously with 0.5 ml. died, and marked signs of infection were observed in all seven birds.

Clinical signs. Roughened feathers, depression, temperature elevation, cyanosis—particularly of the comb and wattles—and conjunctivitis occurred in nearly all birds infected with fowl plague-like virus. Some birds had diarrhea, and vesicles were seen on the comb of one bird (see photograph). Survivors had a thermal response at 4 to 6 days postinoculation, cyanosis, and depression followed by recovery within 10



Vesicles in the comb of a chicken inoculated with fowl plague-like virus (magnified approximately 35 times)

days postinoculation. Thermal reaction in survivors did not exceed 108° F.; chickens that died had thermal reactions to at least 110° F. Cloacal temperatures of birds inoculated with recently passaged fowl plague-like virus reached 109° F. at 72 hours after inoculation. Virulence appeared to decrease following 8 to 10 months' storage at $-30°$ C.; however, virulence was restored following one passage in developing chicken embryos. All birds inoculated with freshly passaged material died 7 days following inoculation: 10 to 60 percent of the birds in other groups survived inoculation with fowl plague-like virus that had been stored for 10 months with no intermediate passage in embryos.

Necropsy. The lesions seen most frequently were catarrhal enteritis and hemorrhages (1 mm. to 3 mm. in diameter) in the proventriculus and in the submucosa of the small intestine. The hemorrhages were not visible from the serous side of the intestine. Lesion areas in the intestines were examined and found to be free of coccidial oocysts. Hemorrhages were observed occasionally on the mucous membrane in the upper two-thirds of the trachea.

Petechial hemorrhages were observed throughout the skeletal muscle, and vesicles developed on the comb and wattles. No bacterial pathogens were found in liver and spleen tissue suspensions.

Histopatholgy. Many villi in the mucosa of the small intestine were detached and there were marked vascular changes. Round cell infiltration was observed in the subcapsular area of the gizzard. Extensive degenerative changes were found in the liver cells.

Inoculation of experimental animals. Three cynomolgus monkeys were inoculated intramuscularly with 10^5 chicken embryo lethal doses of fowl plague-like virus. The monkeys did not show clincial signs, and they were killed at 15 days postinoculation. A slight and transitory thermal response occurred at 4 days postinoculation (table 1). Blood samples collected from monkeys 10 days after inoculation were not infective for chickens.

Ducklings have been reported to be susceptible to fowl plague but not Newcastle disease (*3*). Fifteen ducklings inoculated by the intramuscular route with 10^3 chicken lethal doses of fowl plague-like virus had no clinical signs. Fowl plague-like virus also failed to elicit signs in rabbits, guinea pigs, ferrets, and weanling hamsters.

Serology. Virus neutralization tests in developing chicken embryos were conducted with anti-fowl-plague serum and allantoic fluid from embryos infected with fowl plague-like virus (table 2). Unequivocal evidence of at least a one-way serologic cross between anti-fowl-plague serum and fowl plague-like virus was shown (table 2). Similarly, evidence of a reciprocal cross-reaction was shown (table 3) by neutralization of fowl plague virus with serums from chickens recovered from infection with fowl plague-like virus. The chickens were initially inoculated intramuscularly with fowl plague-like virus from embryos. Ten days after initial inoculation, four survivors were reinfected with fowl plague-like virus passaged from embryo to chicken to embryo. Virus neutralization tests with fowl plague virus were conducted with serum from blood samples taken 12 days after reinfection with fowl plague-like virus. Approximately 10^3 chicken lethal doses of fowl plague virus (Brescia) were neutralized by serum from chickens which had survived inoculation with fowl plague-like virus. Antibodies of fowl plague virus were not detected in serum from the patient's blood samples collected during either the acute or the convalescent stage (table 4).

Table 1. Temperatures of 3 monkeys after intramuscular inoculation with 10^5 chicken embryo lethal doses of fowl plague-like virus

Days postinoculation	Temperature of monkeys		
	No. 6	No. 16	No. 30
1	101. 6	100. 0	101. 0
2	101. 8	100. 4	101. 0
3	101. 0	99. 6	100. 8
4	[1] 101. 8	[1] 102. 0	[1] 102. 6
5	101. 0	100. 4	100. 8
6	101. 8	100. 4	100. 8
7	101. 0	101. 0	101. 4
8	101. 2	101. 4	101. 0
9	101. 0	101. 4	102. 2
10	101. 0	101. 2	102. 0
11	101. 6	101. 2	102. 4
12	101. 6	100. 8	102. 0
13	101. 4	101. 2	101. 9
14	101. 4	101. 6	101. 8
15	101. 6	101. 4	101. 6

[1] Blood taken for viremia test.

Hemagglutination and hemagglutination-inhibition tests. Fowl plague-like virus agglutinated chicken red blood cells in dilutions through 1:80. Anti-fowl-plague serum (Brescia) diluted 1:10 reduced the hemagglutination titer of fowl plague-like virus from 1:80 to 1:5. Serum from a blood sample collected from the human host 4 months after his illness did not reduce the hemagglutination activity of fowl plague virus.

Cross-protection. The Brescia strain of fowl

Table 2. Results of neutralization tests in developing chicken embryos using fowl plague-like virus, fowl plague, and Newcastle disease antiserums

Antiserums	Fowl plague-like virus [1] dilutions						
	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
None	+	+	+	+	+	+	−
Fowl plague (Brescia)	−	−	−	−	−	−	−
Fowl plague (Alexandrien)	+	+	−	−	−	−	−
"N" virus (a fowl plague isolate)	−	−	−	−	−	−	−
Newcastle disease	+	+	+	+	+	−	−

[1] Infected allantoic fluid passed once at Plum Island Animal Disease Laboratory in developing chicken embryos.

NOTE: Plus signs indicate embryos died in 48 hours; minus signs indicate embryos survived.

Table 3. Neutralization of fowl plague virus (Brescia) with serum from chickens after inoculation with fowl plague-like virus

Serum	Fowl plague virus dilutions								
	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}
Normal chicken	(1)	(1)	(1)	(1)	+	+	+	−	−
Fowl plague-like virus antiserum (chicken)	+	−	−	−	−	−	−	−	−

[1] Test not run.

NOTE: Plus signs indicate embryos died; minus signs indicate embryos survived.

Table 4. Assay for fowl plague virus neutralizing antibodies in serums of a patient from whom fowl plague-like virus was recovered

Serum	Fowl plague virus dilutions								
	0	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}
Normal chicken	(1)	(1)	(1)	(1)	+	+	+	+	−
Acute	+	+	+	+	+	+	+	+	−
Convalescent, 5 months after patient's illness	+	+	+	+	+	+	+	+	−
Convalescent, 20 months after patient's illness	+	+	+	+	+	+	+	+	−

[1] Test not run.

NOTE: Plus signs indicate embryos died; minus signs indicate embryos survived.

plague virus was injected into four chickens that had survived two inoculations with 1,000 chicken lethal doses of fowl plague-like virus (table 5). One of the chickens died 4 days postinoculation, a transitory increase in body temperature was noted in two chickens, and one had no clinical signs. The mild reactions of these three birds and their subsequent survival indicated a significant degree of resistance to fowl plague-like virus. Six control chickens, inoculated with 1,000 chicken lethal doses of virus, died with signs and lesions of fowl plague.

Relation to viruses other than fowl plague. After further passage in eggs, the isolate was tested by hemagglutination-inhibition techniques (*4–6*) against the following serums: influenza A Asian, Denver, PR 8, FM1, and swine; influenza B Great Lakes; parainfluenza types 1, 2, and 3; Newcastle disease virus; mumps virus, reovirus type 1, and acute-phase and convalescent-phase serums from the patient. No inhibition of agglutination was noted with any of these serums. The isolate was tested by the diagnostic complement fixation technique (*7*) against the following serums: Eastern equine encephalitis, Western equine encephalitis, vaccinia, herpes simplex, adenovirus 4, and acute-phase and convalescent-phase serums from the patient. No fixation was noted with any of the serums.

Discussion

Although fowl plague-like virus did not prompt an immune response in man, it did elicit antibody response in chickens. This antigenic behavior of fowl plague-like virus agrees with other properties of the virus, indicating that man is an alien host and the chicken is the natural host. Further evidence of host specificity was shown by failure to infect either monkeys, ducklings, rabbits, guinea pigs, ferrets, or weanling hamsters.

The comparative studies between fowl plague-like virus and fowl plague included observations other than serologic, yet there has been no need to reconcile clinical discrepancies with a serologic likeness. The characteristics of the fowl plague-like virus were in such close agreement with those of fowl plague that a diagnosis of fowl plague would have been un-

Table 5. Response of 4 chickens recovered from fowl plague-like virus to intramuscular inoculation with 10^5 chicken lethal doses of fowl plague virus

Days post-inoculation	Temperature of chickens			
	No. 9326	No. 9329	No. 9342	No. 9349
1	108. 4	107. 2	106. 4	108. 2
2	108. 2	109. 0	107. 4	109. 0
3	109. 0	107. 8	106. 8	110. 0
4	(1)	Dead	(1)	(1)
5	106. 4		106. 2	107. 4
6	105. 2		106. 2	105. 8
7	104. 6		105. 8	104. 2
8	104. 0		105. 6	104. 4

[1] Not taken.

questioned had the isolation been made from chickens. Although definite evidence of the patient's exposure to fowl plague virus is lacking, his subsequent recovery may be explained on the premise that the fowl plague-like virus had remained latent until he was infected by a second agent.

Conjecture concerning possible sources of the virus other than blood from the patient prompts a question concerning the initial developing chicken embryos used for inoculation as a possible source. This possibility cannot definitely be excluded, although some embryos from a second group inoculated with the blood died and hemagglutination positive tests were obtained with the allantoic fluid. Furthermore, it did seem unlikely that evidence of infection in chickens would not be detected if infection were present in developing chicken embryos of commercial flocks.

Summary

Fowl plague-like virus isolated from a man was infective for chickens. Clinical signs resembling those of fowl plague developed in the chickens when they were inoculated with blood clot material from the man, who had become ill after a trip abroad. The trip had included visits to areas from which fowl plague had been reported.

Fowl plague-like virus and fowl plague virus elicited neutralizing antibodies for the heterologous as well as the homologous virus. A serologic relationship between the two was also shown by hemagglutination-inhibition tests.

The course of fowl plague-like virus infection in chickens and its clinical signs and lesions were indistinguishable from those seen in chickens infected with fowl plague virus. Chickens that recovered from infection with fowl plague-like virus were refractory to fowl plague virus.

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POSSIBLE ROUTES OF ZINC 65 FROM AN EXPERIMENTAL ESTUARINE ENVIRONMENT TO MAN

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POSSIBLE ROUTES OF ZINC 65 FROM AN EXPERIMENTAL ESTUARINE ENVIRONMENT TO MAN

Thomas W. Duke

Zinc 65 occurs in estuarine environment as fallout from nuclear detonations (1) (2) and as wastes from nuclear reactors (3) (4) (5). This isotope is concentrated by organisms used as seafood by man (6) and by organisms that serve as food for seafood species (7). Therefore, the movement of zinc 65 in the estuarine environment needs to be studied to a greater extent so that the routes and rates by which it could return to man from this environment can be delineated.

The routes and rates of movement of zinc 65 similar to those that occur in the estuarine environment can be studied in the estuary and in the laboratory. More complete information on the relationships between communities of organisms and their environment can be obtained in the estuary since it is difficult, if not impossible, to duplicate estuarine conditions in the laboratory. Zinc 65, however, cannot be released indiscriminately into estuaries because of its potential hazard to man's health. In order to follow the movement of zinc 65 under conditions as natural as possible and to reduce the contamination of seafood, the isotope, in this study, was released into an experimental pond that was connected to an adjoining estuary.

The purpose of this experiment was to determine the routes and rates by which zinc 65 could be returned to man from an experimental estuarine environment and to determine the organisms that could be used as indicators of the presence of zinc 65 in this environment.

Experimental Procedure

A concrete-walled pond 30 × 60 m, adjoining the estuary surrounding Pivers Island, N. C., was used as the experimental environment. The pond contained an undisturbed bottom and was connected to the adjoining estuary by a tile pipe 8 in. (20.3 cm) in diameter. The end of the pipe in the pond was covered with 0.25-in. (0.6-cm) mesh net to prevent migration of larger organisms. Approximately 186 sq m of sediment were covered with water at high tide. The test organisms and other components of the pond are shown in Table I.

Ten millicuries of zinc 65 (specific activity = 0.43 c/g) in the form of ionic zinc in 0.92 N HCl were added to the pond by siphoning a solution of the radioisotope into a stream of water and spraying the stream over the surface of the pond. The salinity of the water at this time was 26.6 ppt, and during the experiment ranged from 24.9 to 34.8 ppt; the temperature was 17°C, and ranged to 29°C; the pH was 7.9, and ranged from 7.7. to 8.2. When the zinc 65 was added, the water in the pond contained 40 mg (wet weight) of suspended material per liter.

Samples of water, biota, and sediment were removed from the pond

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TABLE I.—Components of Experimental Pond

Component	Number	Weight (g)
Marsh grass (*Spartina alterniflora*)	10,000	2.0×10^5
American oysters (*Crassostrea virginica*)	20	3.8×10^3
Hard clams (*Mercenaria mercenaria*)	20	4.6×10^3
Scallops (*Aequipecten irradians*)	20	1.5×10^3
Blue crabs (*Callinectes sapidus*)	15	2.4×10^3
Mud crabs (*Panopeus herbstii*)	10	2.6×10^2
Snails (*Littorina irrorata*)	20	3.8×10^3
Atlantic croakers (*Micropogon undulatus*)	40	1.3×10^3
Mummichogs (*Fundulus heteroclitus*)	20	3.4×10^2
Water		
Low Tide	78 cu m	
High Tide	178 cu m	

periodically and analyzed for zinc 65. The zinc 65 content of the components was measured with a single channel spectrometer and a liquid scintillation detector (11 cm in diameter × 22 cm in length), large enough to hold live animals. Measurements were corrected for decay, geometry, and background radioactivity. Detection of 0.002 μc of zinc 65 per liter of water is possible at the 95-percent confidence level. When the zinc 65 content of the water was below this level, water was reported as containing no zinc 65. Fish were analyzed for 3 min and other samples for 10 min or until 10,000 counts were obtained. Unless otherwise specified, 10 individuals were analyzed separately and the average value was reported. In order that the radioactivity content of the sample may be expressed as specific activity (ratio of zinc 65 to total zinc), three individuals of each species were removed after 100 days and analyzed for total zinc content.

The concentration of stable zinc in the various samples was determined with a dithizone-extraction technique (8) after preliminary preparation of the samples.

Radioecology of the Pond

Zinc 65 moved rapidly from the water to the sediments and to the organisms in the pond and was lost through tidal exchange of water with the adjoining estuary. Of the zinc 65 remaining in the pond after the first day, 36 percent was in the sediments, 5 percent in the biota, and the remainder in the water. One third of the zinc 65 in the water was associated with suspended material. Of the zinc 65 remaining after 100 days, 99.4 percent of the zinc 65 was in the sediment and 0.6 percent in the biota. No zinc 65 could be detected in the water at this time. A more detailed account of the ecology of the pond has been reported (8). The variation in zinc 65 content in each species on the 1st and 60th days after the introduction of the isotope into the pond is shown in Table II. These variations are representative of those on other sampling dates. Maximum levels of zinc 65 in each organism were attained within 2 days (Figure 1). After 100 days the scallops contained 30 percent of this maximum level of zinc 65, oysters 60 percent, and clams 25 percent.

Several components of the pond concentrated zinc 65, demonstrating the routes and quantities of the isotope

TABLE II.—Zinc 65 Content of Organisms in Experimental Pond 1 and 60 Days After Introduction of Isotope

Organism	Whole-Organism Zinc 65 Content* (μμc/g wet wt)	
	1 day	60 days
Oysters	1,111 ± 502 (10)	1,007 ± 515 (10)
Clams	509 ± 166 (10)	287 ± 89 (10)
Mud crabs	853 ± 281 (3)	159 ± 95 (3)
Marsh grass	263 ± 16 (3)	14 ± 6 (5)
Blue crabs	323 ± 172 (5)	150 ± 145 (3)
Mummichogs	379 ± 229 (10)	Not sampled
Croakers	60 ± 46 (10)	108 ± 94 (8)
Scallops	5,561 ± 578 (10)	1,595 ± 218 (3)

* The zinc 65 content is expressed as the mean ±1 standard deviation (number of organisms).

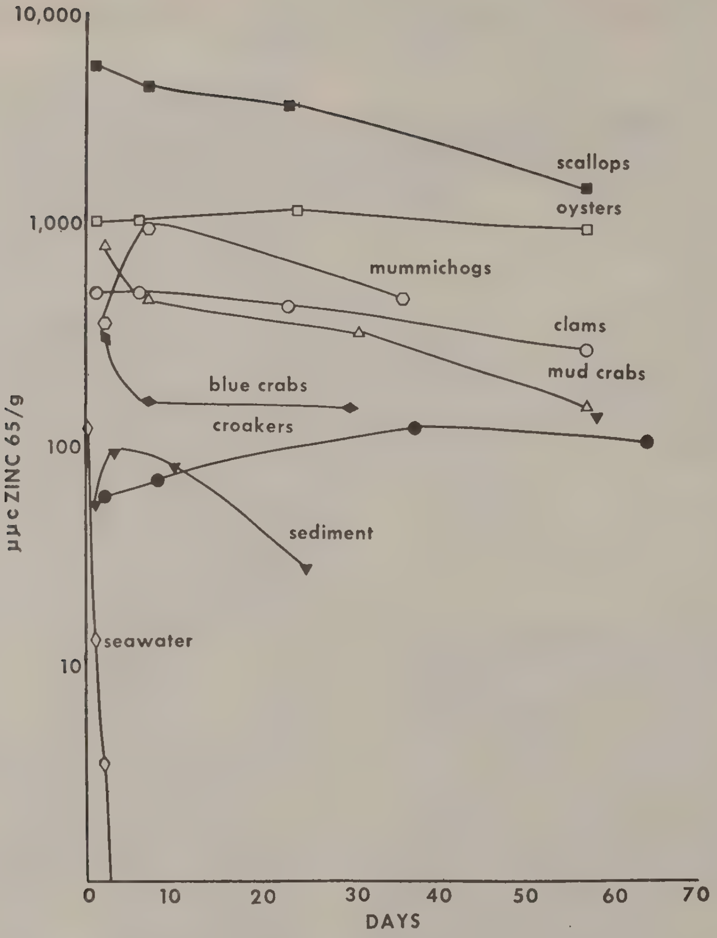

FIGURE 1.—Accumulation of zinc 65 by components of experimental pond.

that can reach man. On a total-weight basis, sediments contained more zinc 65 than other components; but radioactivity in sediments can reach man only indirectly. Scallops, oysters, and clams are eaten by man and they accumulated zinc 65 more rapidly and to higher levels than the other

TABLE III.—Accumulation of Zinc 65 by Scallops, Oysters, and Clams Maintained in an Experimental Pond for 1 Day

Zinc 65 Measurement	Scallop (77 g)*	Clam (230 g)*	Oyster (198 g)*
µµc/organism	428,197±4,280 (10)	117,070±38,000 (10)	219,978±98,100 (10)
% in edible tissue	5±3 (10)	90±4 (3)	73±35 (3)
µµc/edible tissue	21,409	105,363	153,984
Specific activity of edible tissue (µµc Zn^{65}/µg Zn)	14±3 (3)	21±5 (3)	10±4 (3)

* Average wet weight, entire organism, of 10 individuals.

organisms tested. Even though scallops contained more zinc 65 on a whole-animal basis, they would not present the greatest hazard to man as contaminated seafood since only a small part of the scallop, the muscle, is eaten by man. Oysters and clams contained more zinc 65 in edible tissues (Table III) than did the scallops.

The meats of oysters from the experimental pond contained relatively high levels of zinc 65 when compared with oysters that have been exposed to this isotope in the natural environment. Oysters from Willapa Bay, Washington, are exposed to chronic pollution from reactors located on the Columbia River. The amounts of oysters from Willapa Bay and from the experimental pond that one would need to eat in order to obtain the maximum permissible body burden (4) are given in Table IV. These data are for standard sustained consumption and the maximum permissible body burden associated with these rates would be reached only if intake were continuous for three years or more. The calculations are based on 10^{-3} ($\mu c/ml$) as the maximum permissible concentration of zinc 65 in drinking water for occupational exposure. This is equivalent to a sustained intake of about 2.2 μc/day, assuming that the average person drinks 2,200 ml of water per day (9). An average concentration of zinc 65 in oyster meat from Willapa Bay was taken as 5×10^{-5} $\mu c/g$. In contrast, the average concentration in oyster meat from the experimental pond was 7×10^{-2} $\mu c/g$.

TABLE IV.—Amounts of Oysters from Willapa Bay, Washington,* and Experimental Pond Which Must be Eaten to Obtain the Maximum Permissible Body Burden of Zinc 65

Premise*	Sustained Consumption Rate to Give Exposure of Premise (lb/wk)	
	Willapa Bay	Experimental Pond
Occupational Exposure Handbook 69	700	0.7
Persons in the neighborhood of controlled areas†	70	0.07
Suggested I.C.R.P. apportionment for genetic dose‡	7	0.0007
Doubling of natural background§	14	0.014

* (4).

† Taken as 0.1 of values recommended in Handbook 69.

‡ Taking 0.01 of the Handbook 69 values as equivalent to an exposure of 1.5 rem to the gonads in 30 yr. It should be noted that the International Commission on Radiological Protection, for genetic reasons, assumes that the entire population is exposed at this level. The oysters in this case contribute to only a very small fraction of the total population.

§ Assumes that a continuous intake rate of 2.2 μc/day results in 5 rem/yr to the body and that natural background contributes 100 millirem/yr.

Factors Affecting the Pathways of Radionuclides in the Estuarine Environment

The routes by which radionuclides could reach man from estuarine environments depend on many factors such as the manner in which the radionuclide is introduced into the environment, the chemical and physical characteristics of the estuary, rates of turnover of elements in the organisms, and specific activity of seafood organisms and their food (10). Although the interaction of all of these factors is probably more important than the individual influence of any one, it is possible to discuss the manner in which each of these factors might affect routes of zinc 65 in the estuarine environment.

The type of release, chronic or acute, can affect the rate and level of accumulation of the radioactivity by estuarine organisms. When radioactivity is introduced continually over a long period of time (a chronic release), the level of radioactivity in the water will become relatively constant. If radioactivity is released only once (an acute release), the level of radioactivity decreases with time because of dilution, dispersion, and bioaccumulation. The organisms that potentially would be most dangerous to man in the event of a chronic release probably would be different from those which would be dangerous in an acute release. For example, some organisms may concentrate an element to high levels, but a long period of time is required for those with a slow turnover rate of the element. Other organisms may reach maximum levels within a short period of time because of a faster turnover rate. Organisms with slow turnover rates could reach higher levels of radioactivity than those with faster rates if the radioactivity is available over a sufficient period of time. The organisms with the faster turnover rate would, of course, be especially important in the event of acute pollution.

Radioactive materials introduced into the water of an estuary will enter the biogeochemical cycles that operate within the estuary. A portion of the radioactivity will remain in the water and can be dispersed and diluted by the exchange of tidal waters; a portion will be accumulated by the biota; and a portion will be exchanged with stable elements in the sediments and other abiotic substances (8). Rapid exexchange of estuarine water with seawater will result in dilution of radioactivity in the estuary and thus less radioactivity will be available to the biota. Sediments and suspended material will remove radioactivity from the water through adsorption-exchange processes and also will reduce the quantity of radioactivity immediately available to the biota. Changes in environmental factors such as pH, temperature, and salinity can affect the rate and quantity of radioactivity accumulated by the biota (11). For example, at low temperatures the pumping rate of shellfish is reduced and less radioactive food and water pass through the shellfish than under normal conditions. Extreme variations in pH and salinity of the water have a similar effect. Conversely, an increase in temperature a few degrees above the "normal" range will increase pumping rates.

The specific activity of seafood organisms can affect the amount of radioactivity that will reach man (12). The transfer of radioactive material from estuarine water to man often begins with the concentration of the material by plants. The radioactivity then is transferred through a series of organisms that are eating and being eaten (the food chain), and finally may reside in an organism used as food by man. Specific activity of the radionuclide will decrease as it is passed up the food chain because of the dilution of the radioactive elements with stable elements in the organisms, decay of the radioactive material, and slower turnover rates in higher trophic levels. This process has been demonstrated in a community from the Columbia River where the specific activity of phosphorus 32 was lower in organisms near the end of the food chain than in those near the beginning (13). Similar relationships were found in this experiment. However, particular radionuclides may accumulate in certain trophic levels in the food chain because of a tendency of species to concentrate specific elements.

The amount of radioactivity man will accumulate from his food depends on the specific activity and total activity in the food. If radioactive food is being ingested continuously, the specific activities of the isotopes in the food will be more significant than total activity, since the specific activities in man will approach those in his diet. Nevertheless, food with a low specific activity and large quantities of radioactivity could be hazardous. Because of the low specific activity, a radionuclide would have a slow turnover and long residence time in man. Thus, if man were to use the organisms from the experimental pond periodically as food, the organisms with the highest specific activity, i.e., the clams (Table III), would be the greatest potential source of zinc 65. If man were to eat seafood from the pond only once, he probably would receive more radioactivity from the oysters since the meats of the oysters contained the largest quantity of radioactivity.

Indicator Organisms

An accurate and rapid method is needed to determine the amount of radioactivity of the many fission products and neutron-induced radionuclides, such as zinc 65, which find their way into the marine environment. These nuclides often occur in minute amounts. Dilution and dispersion of the nuclides make it difficult to obtain a sufficient quantity of water and sediments for measuring the presence of activity. Under the conditions existing in the experimental pond, scallops were found to be good indicators of the presence of zinc 65 if samples were taken 1 day after the isotope was added to the water. Oysters, however, retained the zinc 65 longer than did scallops and after 100 days contained more of the isotope on a whole-animal basis. Thus, the usefulness of the ''indicator'' depends not only on the capacity of the organism to obtain the isotope rapidly and to concentrate it to high levels but also, in the instances of acute pollution, the capacity to retain the isotope.

Summary

Less than 1 percent of the zinc 65 introduced into the water of the pond was accumulated by seafood organisms. Loss of zinc 65 from the pond through the exchange of pond water with water in the adjoining estuary and absorption of the isotope by sediments greatly affected the accumulation of the isotope by the biota. Shellfish accumulated the isotope rapidly and to higher levels than did other organisms, and the zinc 65 accumulated in the edible portions of these animals easily could have been transferred to man. If all organisms from the pond were eaten by man over a long period of time, he could have accumulated more zinc 65 from clams than other organisms because edible portions of the clams had the highest specific activity. The meats of oysters contained highest levels of zinc 65 and the oysters could have been a potential hazard. Of course, these results cannot be extrapolated to include the possible movement of zinc 65 in an estuary under different environmental conditions of pH, temperature, salinity, and different rates of exchange of water. As these conditions vary, the movement of zinc 65 also could vary.

Acknowledgment

This research was supported through a cooperative agreement between the U. S. Fish and Wildlife Service and the U. S. Atomic Energy Commission.

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Reprinted from
Proceedings of the
GULF AND CARIBBEAN FISHERIES INSTITUTE
Nineteenth Annual Session, November, 1966
59-67

Cycling of Nutrients in Estuaries[1]

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The cycling of nutrients required for the growth and reproduction of estuarine organisms must be understood if we are to manipulate the estuarine environment to obtain maximum production of fish and shellfish. When the cycling of nutrients is interrupted, or when the supply of nutrients is limited, the growth of estuarine primary producers such as phytoplankton and marsh grass is reduced. This reduction can adversely affect the flow of energy through the estuary and the production of fish and shellfish. If levels of nutrients are increased in certain phases of the cycle, however, production is increased. The use of radioisotopes has advanced our understanding of the cycling of nutrient elements. The cycling of carbon, phosphorus, and certain trace metals has been studied with this technique. For example, the movement of zinc, a trace nutrient, has been investigated at the Radiobiological Laboratory. Radioactive zinc was used to follow the movement of this nutrient through the water, biota, and sediments of experimental environments in the laboratory and in tidal ponds. Also, the exchange of this element between water and sediments was measured in an estuary. Sediments act as a reservoir for zinc, which exchanges rapidly between sediments and sea water. It is therefore unlikely that zinc limits estuarine production. Techniques used in this study can be applied easily to investigations of other trace nutrients.

INTRODUCTION

A basic understanding of the cycling nutrients will contribute greatly to man's capability of manipulating estuaries to increase the yield of seafood. Already, estuaries are among the most productive areas in the world and their importance continues to grow with the world's growing populations. As the need for food continues to increase, however, estuarine acreage suitable for aquatic life continues to decrease as a result of pollution, filling, dredging, and other activities of man. Since new estuaries cannot be created, except at great expense, it is urgent that further destruction be stopped and that better utilization of existing estuaries be initiated. The farmer already has experienced a reduction in acreage of his farmland as a result of industrialization and of government crop control. To counteract this reduction, farmers have used good management techniques to increase their total yields despite the decreased acreage. If we are to obtain more seafood from our estuaries we must also use good techniques in managing them.

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[1] This research was supported through a cooperative agreement between the U.S. Fish and Wildlife Service and the U.S. Atomic Energy Commission.

It has been demonstrated repeatedly that small enclosed bodies of water can be manipulated to insure increased yields of fishery organisms. This approach has been exploited successfully in Japan and elsewhere. Many times production has been increased by simply increasing the level of certain inorganic nutrients in the water. Some thought currently is being directed toward increasing production of oceanic waters, but this undertaking would be difficult and expensive because of their enormous size. Nature, however, has provided man with an environment, ranging in size between ponds and the open ocean, which may prove to be adaptable to the techniques of aquaculture — the estuary. In other words, we may be able, in the not too distant future, to manipulate this environment to obtain greater yields of seafood.

Estuarine ecosystems including marshes, tidal creeks, and bays differ from fresh water and marine ecosystems in their relatively high concentrations of nutrients. In contrast to other ecosystems, estuaries can act as nutrient "traps" (Schelske and Odum, 1961). Nutrients entering the estuary from fresh water drainage systems and originating from the decay of marsh plants within the estuary are trapped by physical, chemical, and biological processes. For instance, the mixing of waters of different salinities produces vertical currents which move the nutrients rapidly throughout the water, biota, and sediments and reduce the amounts swept out to sea. Biodeposition is another mechanism by which nutrients are retained. The ribbed mussel, *Modiolus demissus,* deposits great quantities of organic particles as pseudofeces that sink to the bottom (Kuenzler, 1961). Nutrient materials in these particles thus become available to other organisms. Biological processes may be most important, therefore, in retaining nutrients in the estuary.

The large quantities of nutrients trapped in the estuary promote a high rate of plant production. This production is of utmost importance since all animals in the estuary are either directly or indirectly dependent upon the photosynthetic capability of plants. Shallow estuaries, such as those along the Atlantic Coast, have three main groups of primary producers: microscopic algae, seaweeds, and salt marsh phanerogams. These plants supply the organic material that flows through the biota of the estuarine ecosystem. Much of this material never reaches carnivores or the animals used as food by man and thus can be considered "wasted." For example, some organic material is eaten by organisms which are not used as seafood. Frequently, these organisms prey on or parasitize the organisms harvested for food. Thus, two problems confront those concerned with increasing the yield of fishery organisms: (1) increasing the production of organic matter, with which this paper is concerned, and (2) channeling the organic material into food webs that support fishery organisms.

Estuarine water at least part of the time contains inorganic nutrients necessary for high production of organic matter. These nutrients, however, are not always present in the water in proportion to the requirements of the plants, and a lack of sufficient quantities of one or another nutrient often is limiting to the production of organic matter. Further, all of a nutrient present in the water is not always available to plants, since nutrients may occur in complex molecules or coupled to soluble organic compounds which cannot be metabolized. Finally, the level of a nutrient in the water at any given time represents only the net difference between all factors tending to increase the concentration and all factors tending to decrease the concentration. Data on the levels of nutrient present at one particular time give no information on the most important factor — the rate of turnover of the element in the estuary.

STUDY OF NUTRIENT CYCLING WITH RADIOISOTOPIC TECHNIQUES

Determining the rates of flow of nutrients through the estuary is difficult since many nutrients occur in trace amounts. With radioisotopic techniques it is possible to determine not only the rates of movement of nutrients but also their routes of movement. By coupling chemical analysis of the stable element with radioisotopic measurements it is possible to determine if the radioisotope is being distributed in proportion to the abundance of the stable element. This procedure makes it possible to observe the rate of flow and the cycle the element takes in moving throughout the estuary. Information on the rates of movement of several nutrients have been obtained with the radioactive-tracer technique. For example, carbon 14 has been used to determine the rate of production of organic material and the movement of this material through the ecosystem. Other radioisotopes, such as phosphorus 32 and zinc 65, have been used also as tracers in nutrient studies in the laboratory and in the field.

Nutritive elements are cycled continuously through water, sediments, and biota — the three phases of the estuarine environment. Water is the medium of transport for these elements as they move in the environment and the chemical composition of the water influences the physical state of certain elements. Thus, the composition of the water affects the availability of these elements to the biota. Although the concentrations of many elements in estuarine water are small, they are in equilibrium with large reservoirs in the sediment and suspended material in the water. The ease with which shallow water can be stirred and mixed increases the importance of exchange of elements between estuarine sediments and water to such an extent that the sediments may have a major influence on the routes and rates of movement of nutrients. Nutrients sorbed onto sediment particles under certain conditions are available to the biota. Sediment-sorbed nutrients can occur again in the water and be accumulated by the biota by absorption and adsorption. Although animals accumulate nutrient elements from the water, most of their nutrient requirements are obtained from food. A portion of the nutrients accumulated by the biota is returned to the environment through excretion and through decomposition of organisms after death. The nutrient cycle in an estuary can be described as the movement of nutrients through the three phases superimposed upon the movements of these phases. For example, the sorption of a nutrient onto a sediment particle suspended in the water represents the movement of a nutrient, but the injestion of the particle containing the nutrient by an organism represents the movement of one of the three phases. A simplified schematic diagram of a typical nutrient cycle in an estuary is shown in Fig. 1.

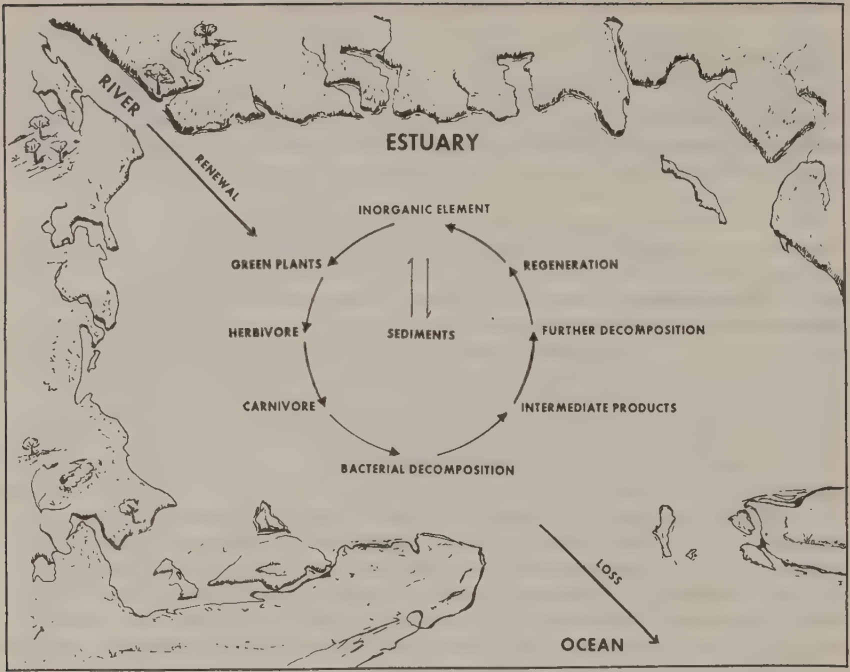
RIVER
RENEWAL
ESTUARY
INORGANIC ELEMENT
GREEN PLANTS
REGENERATION
HERBIVORE
SEDIMENTS
FURTHER DECOMPOSITION
CARNIVORE
INTERMEDIATE PRODUCTS
BACTERIAL DECOMPOSITION
LOSS
OCEAN

FIG. 1. Simplified schematic diagram of a nutrient cycle in an estuary.

Carbon Cycle

The carbon cycle is one of the better known nutrient cycles in the aquatic environment. Carbon, which occurs in sea water as CO_2, HCO_3^- and covalently bound in certain soluble compounds, is converted into organic material by photosynthetic plants. Plant materials are transferred to herbivores that graze upon them. These herbivorous animals are then preyed upon by carnivorous animals. Plants and animals which are not eaten release their contained carbon to the environment upon death. Carbon accumulated by animals also is returned to the water by respiration and excretion. The release of carbon by living and dead plants and animals accounts for a large portion of the total organic carbon present in sea water. Expressed on a relative scale with 100 equaling the amount of soluble organic matter in sea water, the total organic matter approximates the following distribution: soluble organic 100; particulate detritus 10; phytoplankton 2; zooplankton 0.2; and fish 0.002 (Parsons, 1963). This distribution is for the oceanic environment and probably would differ somewhat from the distribution in estuaries. No similar data, however, are available for the estuary. Relatively little is known about the rate at which carbon is produced in an estuary and even less about the movement of soluble and particulate carbon. Carbon 14 has been used as a tracer to investigate these problems in the oceans.

Carbon 14 has been used to observe the influence of bacteria on the movement of organic material between sediments and sea water (Duke, Ibert, and Rae, 1961). A naturally occurring spectrum of carbon 14-labeled organic material was sorbed onto montmorillonite clay and the loss of the carbon 14 from the clay in the presence and absence of marine bacteria was compared. The organic material was prepared by growing phytoplankton in synthetic sea water containing $BaC^{14}0_3$ and then extracting the labeled organics from the cells. Flasks containing clay slurry labeled with the carbon 14 organics were inoculated with marine bacteria and placed on a rotary shaker. After 7 days, the carbon 14 of inoculated clay was compared with that of the clay in flasks containing no bacteria (control). Some of the bacteria increased the removal rate in the 7-day period by a factor of about two (Table 1). Occurrence of such a phenomenon in nature would make sediment-sorbed materials more available to the biota.

TABLE I

EFFECT OF BACTERIA ON THE MOVEMENT OF CARBON 14-LABELED ORGANICS FROM CLAY TO SEA WATER AFTER INCUBATION FOR 7 DAYS[1]

Bacteria strains	Carbon 14[2] cpm/ml	Amount removed (percent)
No bacteria (control)	1,089	0
10 BGP (Pseudomonadaceae)	469	51
14 TA (Pseudomonadaceae)	536	51
18 TGA (Brevibacteriaceae)	639	41
19 TG (Pseudomonadaceae)	668	39
16 TG (Achromobacteriaceae)	753	31
16 TGB (Achromobacteriaceae)	831	24

[1] Data taken from Duke, Ibert, and Rae (1961).
[2] Average carbon 14 content of clay from three experiments.

A sensitive method for measuring primary productivity became available with the production of radioisotopes (Steemann Nielsen, 1952). By this method the rate at which energy is accumulated in the form of organic matter can be calculated from the net mass of carbon fixed per unit of time per unit volume of water. An adaptation of this method has been used to estimate benthic productivity (Grontved, 1960). Core samples, suspended in filtered sea water containing $HC^{14}O_3$, are maintained in sunlight and shaken periodically. After 2 hours, a sample is filtered. From the proportion of carbon 14 on the filter, Grontved calculates "potential production" and suggests that real production is about one-half this amount. This method for measuring benthic production is sensitive and relatively simple to apply. Application of these methods to estuarine waters will provide estimates of total organic production which is potentially available to fishery organisms through the carbon cycle.

Phosphorus Cycle

Phosphorus and carbon are related with respect to the regeneration and assimilation of nutrients. These elements and nitrogen occur in sea water in a nearly constant ratio (C:N:P = 41:7:1 grams). Also, the ratios of the three elements in plankton are very nearly the same. For many years the low concentration of phosphorus has been known to be a factor limiting the growth of phytoplankton in the sea. Studies in the laboratory with pure cultures, as well as work in the field, have shown that phosphorus often is deficient where blooms of phytoplankton do not occur or are short-lived. That the phosphorus concentration of the medium decreases following an increase in the phytoplankton population has been relatively easy to demonstrate in the laboratory. Detection of phosphorus exchange, however, was not possible until tracer techniques for radioactive phosphorus were developed. Using these techniques, Rice (1953) investigated the exchange of this important nutrient between sea water and phytoplankton. Phytoplankton cells which had accumulated phosphorous 32 were placed in a medium which was continually renewed and contained only stable phosphorus. The appearance of radioactive phosphorus in this medium indicated that phosphorus exchange had occurred. When the cells were maintained in the light the rate of movement of the radioactivity was rapid at first and then decreased with time; after 14 days, 6.97% of the total radioactivity contained in the cells had been exchanged to the medium. When the radioactive cells were maintained in the dark, only 3.26% of the phosphorus 32 in the cells exchanged with the medium in 14 days.

The exchange of phosphate between estuarine water and sediment also has been studied experimentally with phosphorus 32 (Pomeroy, Smith, and Grant, 1965). This exchange consisted of a two-step ion exchange between clay minerals and water, plus an exchange between interstitial microorganisms and water. Biological exchange was insignificant in undisturbed sediments but in suspended sediments biological exchange moved nearly as much phosphate as was exchanged with clay minerals. These results confirm the suggestion that sediments act as a buffer on the phosphate content of estuarine water. Rates of exchange and the exchange capacity of the sediments appeared to be large enough to maintain phosphate at a level favorable to plant production, even though phytoplankton blooms and tidal flows tended to decrease the concentration of phosphorus in the water.

Zinc Cycle

Of the three nutrient cycles discussed in this paper, least is known about the zinc cycle. It is known, however, that zinc does occur in all three phases of the estuarine environment. In water, this element is postulated to exist mostly in the ionic state but some zinc also occurs in a complexed form. In the sediment phase, zinc probably occupies spaces in the lattice structure of clays or is sorbed onto surfaces or interfaces of other sediment particles. Zinc is relatively abundant in several species of marine organisms and is essential for their growth and reproduction. This element is sorbed onto mucous surfaces and is specifically bound to enzymes, such as carbonic anhydrase and alcohol dehydrogenase. Although zinc occurs in minute quantities in sea water, observations have been made on its movement through estuarine communities maintained in experimental ponds and in the laboratory.

The movement of zinc through the water, sediments, and macrobiota of two experimental estuarine ponds was followed with zinc 65 as a tracer (Duke, Willis, and Price, 1966). One pond was essentially a closed system, whereas the other was connected to an adjoining estuary. In the closed system, zinc 65 introduced into the water of the pond moved rapidly from the water to other components of the ecosystem. After 1 day only 66% of the zinc 65 remained in the water. In the open system, 82% of the zinc 65 was flushed out of the pond within 1 day by tidal exchange of water. Of the zinc 65 remaining, 36% was in the bottom sediments, 59% in the water, and 5% in the macrobiota. The filter feeding mollusks—oysters, clams, and scallops—in both ponds accumulated more zinc 65 and contained more stable zinc per unit weight than did blue crabs, mud crabs, snails, croakers, and cord grass—the other organisms in the pond. After 100 days, the bulk of the zinc 65 and stable zinc was in the sediment in both ponds. Analysis of the ratio of zinc 65 to stable zinc (specific activity) in components of the ecosystem indicated that the exchange of zinc between sediments and water controlled the movement of this element in the ponds. Evidently, sediments may act as a reservoir for zinc in the estuarine environment.

Movement of a nutrient, such as zinc, through the estuarine ecosystem and its availability to the biota depends in part on the chemical state of the nutrient in the water. Therefore, if zinc were complexed with organic material in sea water, organisms might accumulate it at different rates and to different levels than if the zinc were not complexed. To test this possibility, communities of organisms and sediments were exposed to zinc 65 in sea water in a complexed and uncomplexed state (Annual Report, Radiobiological Laboratory for fiscal year ending June 30, 1963; Circular 204). Zinc 65 in the form of ionic zinc in HC1 was added to sea water containing EDTA (ethylene diamine tetraacetic acid) and the water was flowed through a tank containing oysters, clams, and samples of montmorillonite clay. Water containing an equal amount of zinc 65 but without the chelating material was flowed through another tank that contained the same species of organisms and same type of sediment. After 21 days, sea water without zinc 65 was flowed through both tanks so that the loss of the isotope from the organisms and clay could be observed. There was a difference in the rates and levels of accumulation of zinc 65 by organisms and clay in the two tanks (Fig. 2). For example, oysters maintained in water without chelate (tank 1) accumulated 24 times as much zinc 65 in 21 days as did those maintained in water containing the chelate (tank 2). The loss of the isotope from the organisms in the two tanks also was different. After 21 days in the loss phase of the experiment, oysters in tank 2 lost twice as much of their zinc 65 content as oysters in tank 1. Evidently, biological uptake and loss of zinc was affected by the chemical state of the element in the sea water.

SUMMARY

Fishery production in the estuarine environment can be increased by increasing primary production of organic material. If methods can be developed for channeling the organic material into food chains of commercially important species, then fishery production can be increased to the maximum. Primary production is frequently limited by a lack of sufficient quantities of a particular nutrient. In these situations, simply supplying this nutrient in adequate amounts will increase production to

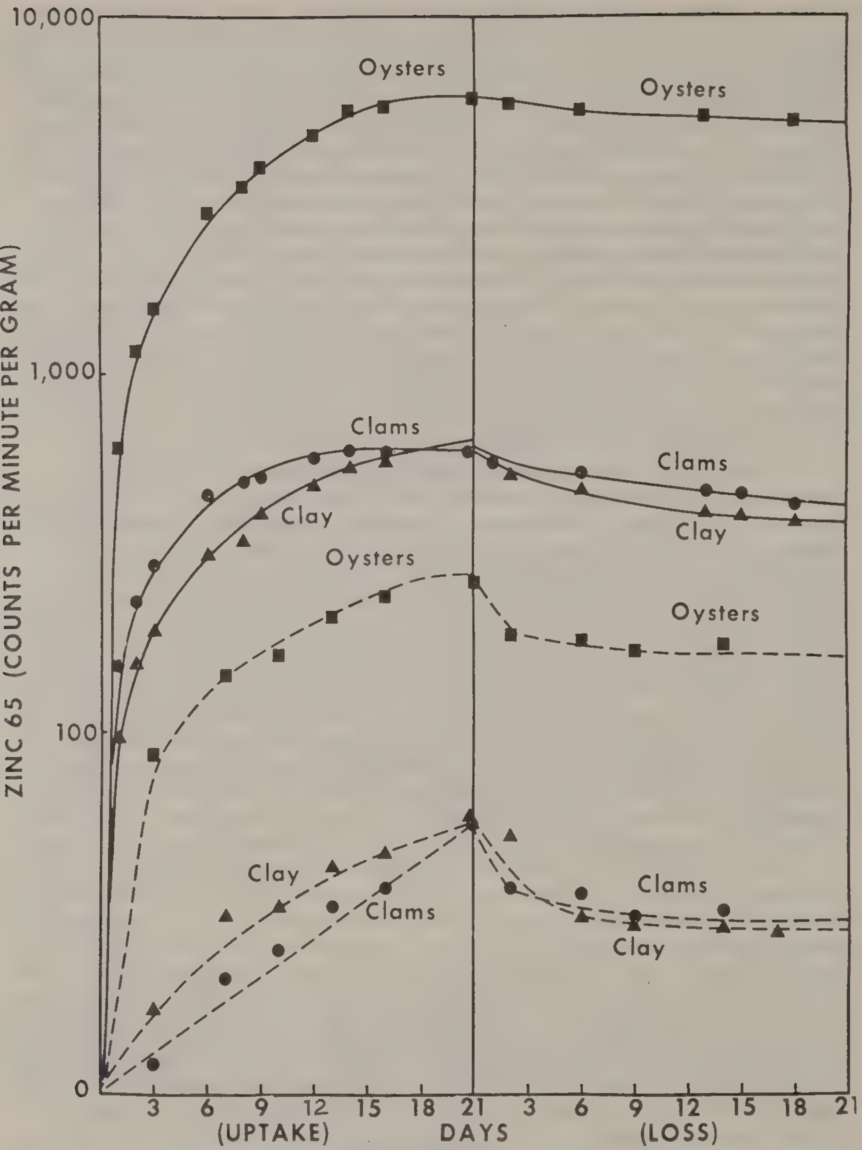

FIG. 2. Effect of EDTA on uptake and loss of zinc 65 by oysters, clams, and clay samples. Broken lines represent uptake by animals and clay maintained in water containing the chelate.

a level where some other factor becomes limiting. To be able to supply the right nutrients in proper amounts will require more data on their availability to plants, the rates of turnover of the nutrients in each reservoir, and the routes taken by nutrients as they move through the ecosystem. Nutrient cycles in the estuary must be understood—and understanding of the cycling of a nutrient will require an extensive investigation into the various dynamic aspects of estuarine ecology. Once this information is available, more effort can be directed toward channeling organic material into seafood organisms.

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Studies of the Exchange of Trace Elements Between Estuarine Sediments and Water

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A radioisotopic technique was developed for the study of elemental exchange between cores of estuarine sediments and overlying estuarine water. Sediments are collected in a coring device constructed with a lucite cylinder which is plugged and detached after a core is taken. After equilibration of the cores with estuarine water, the cylinder is slipped into the well of a lead shield constructed so that radiation from only a narrow wedge of the water column is measured. Radioactive tracer is added to the water in the cylinder and the concentration of radioactivity, measured with a 3-inch crystal and single-channel spectrometer, is recorded instantaneously and continuously. Exchange rate on an areal basis is calculated from the initial specific activity and loss of the isotope from the water. The exchangeable amount of the element in the sediment is determined from the specific activity in the water after the tracer in the water has equilibrated with the sediments.

Reprinted from *The ASB Bulletin,*
Vol. 14, No. 2, April 1967, p. 27.

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BIOLOGY OF THE FRESHWATER DRUM IN WESTERN LAKE ERIE

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ABSTRACT

Information on the biology of the freshwater drum or sheepshead (*Aplodinotus grunniens*) was collected in Lake Erie during a fishery and limnological study made by the Bureau of Commerical Fisheries in 1957 and 1958. Growth of the sheepshead in 1958 was slower than in 1927, and slower than the growth in most other waters. Males and females grew at the same rate through the 4th year of life, but thereafter the females grew faster. Males required more than 13 years and females 11 years to reach 17 inches. A weight of 2 pounds was attained in the 12th year of life by males and in the 10th year by females. Annulus formation extended from mid-June to early August for age-groups I–IV (2nd through 5th year of life). Younger fish started growth earlier in the season than the older fish, and the larger, faster growing members of an age group began growth earlier than the smaller fish.

The growing season in 1958 ended in early October. Bottom-water temperatures were about 65°F when growth started (mid-June) and 58°F when growth ended. Growth was most rapid in August when temperatures were highest for the year (72°F). Growth of young of the year, but not that of older fish, was positively correlated with temperature during the 1951–57 growing seasons. The sex ratio of the 1958 samples shifted with age; age-groups I–IV contained 54% males, but older age groups had 75% males. Males matured between 7.0 and 15.9 inches (age-groups II–V) and females between 9.0 and 13.4 inches (age-groups III–VII). Spawning in 1958 reached a peak in early July, but extended from mid-June to early August.

INTRODUCTION

Growing concern over major changes in the commercial fishery in Lake Erie prompted the Bureau of Commercial Fisheries to undertake a fishery and limnological survey in 1957–58 with the research vessel *Cisco* to study the distribution, abundance, and biology of the fishes and to measure environmental conditions. The present paper, based on the data gathered during this survey, deals with the biology of one of the most important species in western Lake Erie, the freshwater drum, or sheepshead (*Aplodinotus grunniens*).

Although not highly regarded as a food or sport fish, the freshwater drum has become increasingly important in Lake Erie as stocks of more desirable species have declined or disappeared, and because of the increased demand for drum for animal food. The drum also may occupy a prominent position in the ecology of Lake Erie, because it is one of the most abundant species in the western basin of the lake and competes strongly with other major species. Drum made up 21% by weight of the total catches in bottom trawls by the *Cisco* in western Lake Erie in 1958 and were second only to yellow perch (*Perca flavescens*), which made up 55%. Carp (*Cyprinus carpio*), American smelt (*Osmerus mordax*), and emerald shiners (*Notropis atherinoides*) each made up about 5% of the catch,

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[1] Manuscript received October 19, 1966.

THE OHIO JOURNAL OF SCIENCE 67(6): 321, November, 1967.

and 30 other species, including many important sport and commercial species, contributed less than 2% each to the total. A study of the food habits of 10 important fishes from western Lake Erie, collected during the 1957–58 survey, demonstrated that smaller drum feed heavily on most of the invertebrate organisms that other forage, sport, and commercial fish depend upon, and that larger drum, like the majority of other species, feed to a considerable extent on small fish (Price, 1963). Drum, however, are eaten infrequently by other fishes. Consequently, the large population in western and west-central Lake Erie represents an important reservoir of competitive and predatory liability that is not subject to control through predation by other fish.

MATERIALS AND METHODS

Materials for this study were collected during 10 cruises of the research vessel *Cisco* in Lake Erie in 1958. Eleven stations in various ecological areas of western and west-central Lake Erie were visited during each cruise (fig. 1). Drum were collected with bottom trawls, patterned after conventional 2-seam North Atlantic semiballoon trawls. Head and foot ropes were 39 and 51 feet long, respectively; meshes were 3½ inches (extended measure) in the wings and 2½ inches in the body. The cod end was ½-inch mesh and 8 feet long. Trawls were dragged along the bottom parallel to the contours in what were generally 10-minute tows. A temperature profile from the surface to the bottom was obtained with a bathythermograph each time a station was visited.

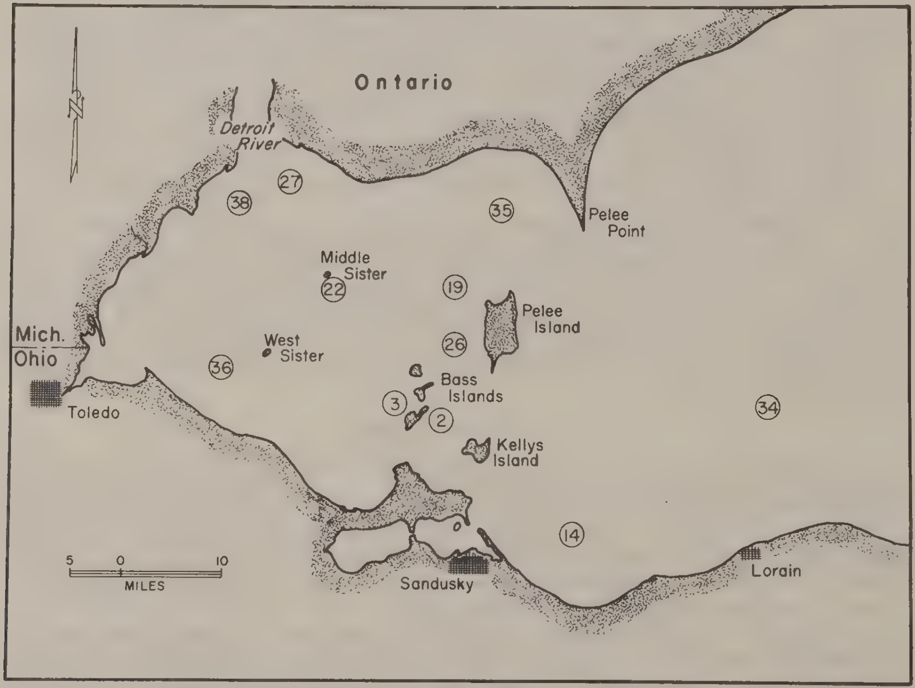

FIGURE 1. Western and west central Lake Erie showing stations of R/V *Cisco* at which data for this study were obtained.

Representative samples of young-of-the-year drum were measured and preserved for later verification of age. Scale samples for the determination of age and the back calculation of growth were taken randomly from the catches of older fish. Scales were taken midway between the lateral line and the midpoint of the spiny dorsal fin, and were placed in an envelope on which were recorded the length, weight, sex, condition of gonads, date, and location. Total length was recorded to the nearest 0.1 inch, and weight in pounds and ounces for fish heavier than 1 pound and in ounces and tenths of ounces for smaller fish. Sex and state of maturity were judged by gross examination, and classified by the criteria of Daiber (1953). Impressions of scales were made in cellulose acetate (Smith, 1954) and were examined at a magnification of 42x with a microprojector (Moffett, 1952). Scale measurements for the calculation of growth were made along the anterior radius of the anterior-posterior axis of the scale.

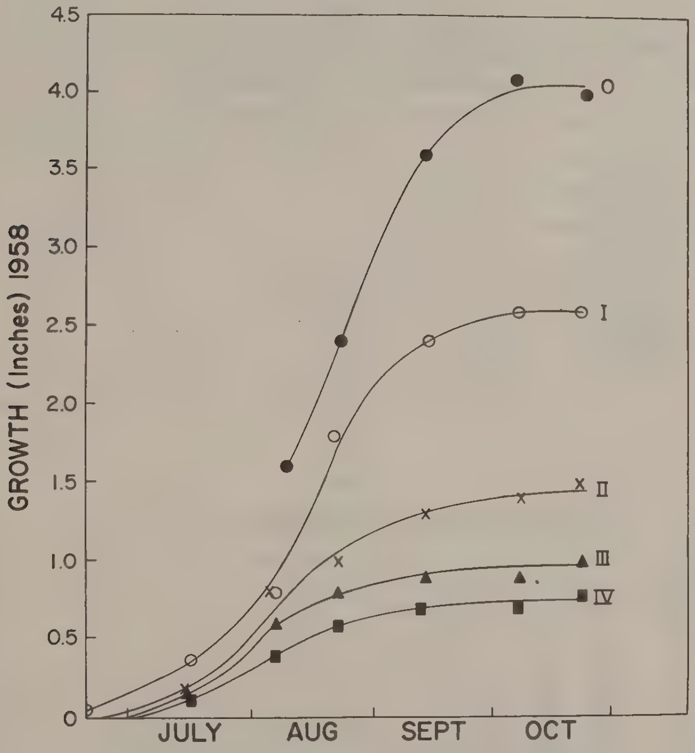

FIGURE 2. Growth in length (inches) of freshwater drum of age-groups 0–IV in 1958. Roman numerals identify the curve of each age group; curves were drawn by inspection.

Ages were recorded as the number of annuli on the scale. Fish with no annulus made up age-group O; those with one annulus, age-group I; those with two annuli, age-group II; . . . . Fish were considered to pass into the next higher age group on January 1 (Hile, 1948).

Of the 1,684 drum in age-group I and older from which scales were examined, 1,505 were assigned ages. A group of 171 drum captured during cruise 7 at stations 2, 3, 14, and 35 was not used because of difficulty in determining if these fish had grown during the calendar year of collection. Eight fish captured at various other times also had scales that were "unreadable." All analyses for fish in age-groups I and older were based on data from the 1,505 fish for which ages were determined (table 1). Of these, 600 were males, 492 were females, and 413 were immature fish for which sex could not be determined in the field. Growth analyses for 1,562 O-group fish were based on length at time of capture (table 2).

LENGTH AND AGE COMPOSITION

The length distributions of male and female drum in various collections were closely similar (table 3). The average lengths, for all cruises combined, were 11.3 inches for males, 11.2 inches for females, and 6.8 inches for the young unsexed fish.

The average length of drum changed little throughout the period of collection, except for the unsexed fish, which increased irregularly from 5.3 inches in the spring (cruises 2–4) to 8.1 inches in the late fall (table 3). Differences in the lengths of males or females during the period of collection were small and showed no seasonal trend. The mean length varied among cruises from 10.6 inches to 12.2 inches for males, and from 10.8 inches to 12.1 inches for females. With the exception of the females of cruises 2–4, the range of the modes was narrow (10.5–10.9 inches to 11.5–11.9 inches) and was identical for the sexes. Length differences between males and females during the same cruise were smaller than the seasonal variation for either sex. The greatest difference in average length between the

TABLE 1

Number of drum in age-groups I and older captured in 1958 from which scales were taken for age and growth analysis

Cruise number	Cruise dates	Station number									Total
		2	3	14	22	27	34	35	36	38	
2	April 13–28	—	—	—	9	—	—	—	—	—	9
3	May 6–19	1	24	—	—	—	14	—	—	—	39
4	May 27–June 8	4	13	5	9	—	—	16	3	—	50
5	June 17–30	48	81	55	48	8	2	39	57	1	339
6	July 9–21	22	28	9	50	—	—	54	37	32	232
7	July 29–Aug. 11	—	—	—	50	—	—	—	17	—	67
8	August 19–30	49	—	20	50	—	—	22	50	—	191
9	Sept. 9–22	50	—	50	17	—	56	55	43	—	271
10	Sept. 30–Oct. 13	51	—	50	—	—	—	45	1	—	147
11	Oct. 21–31	50	—	—	38	—	50	22	—	—	160
Total		275	146	189	271	8	122	253	208	33	1,505

TABLE 2

*Number of age-group 0 drum measured for growth analysis**

Cruise number	Station number										Total
	2	3	14	19	22	26	34	35	36	38	
7	—	—	—	—	—	49	—	—	—	—	49
8	9	—	—	53	56	61	—	—	127	—	306
9	47	44	63	49	58	46	—	57	41	—	405
10	88	52	126	—	4	—	7	42	58	2	379
11	71	68	26	59	26	23	34	62	54	—	423
Total	215	164	215	161	144	179	41	161	280	2	1,562

*Cruise dates are given in table 1. No age-group 0 fish were captured before cruise 7.

TABLE 3

*Length distribution of Lake Erie drum**

Length interval (inches)	Cruise																								Total		
	2–4†			5			6			7			8			9			10			11					
	M	F	U	M	F	U	M	F	U	M	F	U	M	F	U	M	F	U	M	F	U	M	F	U	M	F	U
3.0–3.4	—	—	4	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5
3.5–3.9	—	—	2	—	—	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10
4.0–4.4	—	—	8	—	—	25	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	36
4.5–4.9	—	—	3	—	—	19	—	—	3	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	27
5.0–5.4	—	—	2	—	—	9	—	—	5	—	—	4	—	—	2	—	—	1	—	—	—	—	—	—	—	—	23
5.5–5.9	—	—	4	—	1	5	—	—	1	—	—	3	—	—	5	—	—	3	—	—	—	—	—	—	—	1	21
6.0–6.4	—	—	—	—	—	11	—	—	1	—	—	2	—	—	9	—	—	7	—	—	—	—	—	1	—	—	31
6.5–6.9	—	—	3	—	1	15	—	—	1	—	—	1	—	—	3	—	—	10	—	1	5	—	—	4	—	2	42
7.0–7.4	1	1	2	1	5	18	—	—	9	—	—	1	—	—	3	2	1	12	1	—	13	1	—	4	6	7	62
7.5–7.9	1	2	3	4	5	20	1	2	8	1	4	1	—	3	5	10	5	12	2	1	6	2	2	7	21	24	62
8.0–8.4	1	—	—	8	2	5	4	2	5	—	1	—	—	3	10	5	1	11	7	1	8	3	6	2	28	16	41
8.5–8.9	—	—	—	5	6	5	2	4	2	1	1	—	4	5	10	6	8	3	3	4	2	2	3	—	23	31	22
9.0–9.4	3	2	—	5	4	—	6	3	2	—	—	—	3	3	4	10	7	3	6	3	1	7	1	2	40	23	12
9.5–9.9	5	1	—	10	5	—	9	5	3	4	2	—	8	3	2	5	3	1	4	3	2	6	4	3	51	26	11
10.0–10.4	5	—	1	11	8	—	11	8	1	2	1	—	3	6	1	13	5	—	1	3	1	5	3	2	51	34	6
10.5–10.9	5	4	—	12	13	—	15	12	—	5	7	—	7	4	—	18	7	—	8	5	—	6	7	1	76	59	1
11.0–11.4	6	1	—	13	15	—	15	15	—	2	4	—	7	12	—	15	8	—	5	5	—	2	5	—	65	65	—
11.5–11.9	5	1	—	8	8	—	11	13	—	—	2	—	10	10	—	10	10	—	6	2	—	11	4	—	61	50	—
12.0–12.4	1	2	—	6	4	—	5	3	—	3	1	—	7	4	—	8	8	—	3	—	—	7	4	—	40	26	—
12.5–12.9	—	—	—	3	6	—	8	8	—	3	—	—	3	4	—	3	6	—	3	1	—	6	6	—	29	31	—
13.0–13.4	1	5	—	4	5	—	3	3	1	2	1	—	4	3	—	2	5	—	4	1	—	5	2	—	25	25	1
13.5–13.9	1	2	—	2	4	—	2	3	—	1	1	—	5	3	—	5	4	—	4	1	—	2	2	—	22	20	—
14.0–14.4	—	2	—	1	1	—	2	2	—	—	1	—	1	1	—	3	1	—	1	3	—	2	2	—	10	13	—
14.5–14.9	1	2	—	1	2	—	1	—	—	—	—	—	1	1	—	2	—	—	2	3	—	1	3	—	9	11	—
15.0–15.4	—	—	—	—	4	—	3	2	—	—	1	—	1	—	—	2	—	—	1	—	—	2	—	—	9	7	—
15.5–15.9	—	—	—	1	1	—	1	1	—	—	—	—	—	1	—	4	—	—	1	1	—	—	1	—	7	5	—
16.0–16.4	—	1	—	—	2	—	—	—	—	1	1	—	1	1	—	1	—	—	—	—	—	—	—	—	3	5	—
16.5–16.9	2	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1	—	—	—	—	—	1	—	—	5	—	—
17.0–17.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	2	1	—	5	1	—
17.5–17.9	—	1	—	—	—	—	—	—	—	1	—	—	—	1	—	—	1	—	1	1	—	1	—	—	3	4	—
18.0–18.4	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	2	1	—	3	2	—
18.5–18.9	1	—	—	—	—	—	1	1	—	—	—	—	—	—	—	1	—	—	1	1	—	1	—	—	5	2	—
19.0–19.4	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	1	1	—
19.5–19.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	—	—
20.0–20.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	—	—
22.0–22.4		—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Total	39	27	32	95	103	141	100	87	45	26	28	14	67	70	54	127	80	63	69	40	38	77	57	26	600	492	413
Average length	11.1	12.1	5.3	10.6	11.1	6.0	11.2	11.3	7.3	11.6	10.9	5.8	11.6	11.4	7.6	11.0	10.8	7.4	12.2	11.4	8.0	12.0	11.4	8.1	11.3	11.2	6.8

*M=Male, F=Female, U=Undetermined sex; cruise dates are given in table 1. †Data from cruises 2, 3, and 4 were combined because few fish were taken.

TABLE 4

*Age composition of Lake Erie drum**

Age group	Cruise																								Total		
	2–4†			5			6			7			8			9			10			11					
	M	F	U	M	F	U	M	F	U	M	F	U	M	F	U	M	F	U	M	F	U	M	F	U	M	F	U
I	—	—	23	—	1	75	—	—	14	—	—	12	—	3	22	13	5	44	6	2	30	5	5	16	24	16	236
II	3	3	8	15	16	64	4	7	25	1	6	2	8	13	28	25	21	17	14	11	7	13	14	8	83	91	159
III	12	4	1	25	18	2	21	14	5	8	5	—	17	16	4	28	19	2	15	11	1	17	7	1	143	94	16
IV	17	7	—	38	41	—	46	47	1	9	12	—	23	25	—	34	29	—	15	5	—	20	21	1	202	187	2
V	2	1	—	5	8	—	14	8	—	5	1	—	3	5	—	7	3	—	3	5	—	6	1	—	45	32	—
VI	1	11	—	10	15	—	9	9	—	1	3	—	10	4	—	9	2	—	6	3	—	6	8	—	52	55	—
VII	1	1	—	1	1	—	2	1	—	1	—	—	1	—	—	4	—	—	1	1	—	3	1	—	14	5	—
VIII	—	—	—	1	—	—	3	—	—	—	—	—	1	2	—	2	—	—	2	—	—	—	—	—	9	2	—
IX	1	—	—	—	2	—	—	—	—	—	1	—	2	—	—	3	—	—	1	2	—	1	—	—	8	5	—
X	1	—	—	—	—	—	—	—	—	1	—	—	—	1	—	—	1	—	3	—	—	2	—	—	7	2	—
XI	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	3	—	—
XII	—	—	—	—	1	—	1	—	—	—	—	—	—	1	—	1	—	—	1	—	—	2	—	—	5	2	—
XIII	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	1	—	—	2	—	—	—	—	—	5	—	—
XIV	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Total	39	27	32	95	103	141	100	87	45	26	28	14	67	70	54	127	80	63	69	40	38	77	57	26	600	492	413
Average age	4.2	4.6	1.3	3.7	4.1	1.5	4.3	4.1	1.8	4.2	3.8	1.1	4.4	3.8	1.7	3.7	3.2	1.3	4.2	3.6	1.2	4.2	3.5	1.5	4.1	3.8	1.5

*M = Male, F = Female, U = Undetermined sex; cruise dates are given in table 1.

†Data from cruises 2, 3, and 4 were combined because few fish were taken.

sexes (1.0 inch) occurred in cruises 2–4 and the largest difference in modal length (also 1.0 inch), excluding the females of cruises 2–4, was in cruises 9 and 11.

The age distributions of male and female drum differed significantly. The average age was 4.1 years for all males and 3.8 years for the females, but age-group IV was the modal age for both sexes (table 4). The oldest males were age XIII, and the oldest female was in age-group XIV. The immature fish of undetermined sex were mostly in age-groups I and II, but a few were in age-groups III and IV. The equal division of males and females in age-groups I and II (107 of each sex) suggested that identification of sex in small fish was not easier for one sex than for the other. Thus the difference in mean age of males and females probably was real.

No well-defined seasonal trend in age composition was apparent (table 4), but the mean and modal ages fluctuated among collections. The average age of unsexed fish varied between 1.1 and 1.8 years, and the modal age between age-groups I and II. Age-group IV was dominant for both sexes in all except

TABLE 5

*Relation between total length of fish and magnified scale radius of Lake Erie drum**

Number of fish	Average length of fish	Average scale radius
4	3.2	2.4
5	3.7	3.1
17	4.2	4.0
11	4.7	4.7
11	5.2	5.1
11	5.7	5.9
7	6.3	6.8
17	6.7	7.1
26	7.2	8.2
43	7.7	8.7
27	8.2	9.8
28	8.7	10.4
29	9.2	10.8
29	9.7	12.1
37	10.2	12.4
48	10.7	13.0
47	11.2	13.9
44	11.7	14.9
25	12.1	15.5
19	12.7	16.3
23	13.2	16.8
13	13.6	18.2
12	14.2	18.8
8	14.6	19.9
6	15.2	19.9
5	15.7	21.5
4	16.2	21.3
3	16.6	21.4
3	17.2	24.3
2	17.8	26.0
2	18.4	25.6
2	18.6	24.1
2	19.2	25.6

*Scale radii in millimeters ×42; lengths are true means for 0.5-inch intervals.

cruise 10, when males were most abundant in age-groups III and IV and females in age-groups II and III. The mean age fluctuated, however, ranging from 4.4 years (cruise 8) to 3.7 years (cruises 5 and 9) for males and from 4.6 years (cruises 2–4) to 3.2 years (cruise 9) for females. The seasonal fluctuations in average age of males followed closely those of the females.

BODY-SCALE RELATION

The body-scale relation was determined from scales of 570 drum selected randomly for representation over a wide range of length (table 5). Average anterior scale radii were measured for two or three (average of 2.8) scales from each fish. A plot of average lengths and radii for fish by 0.5-inch-length intervals indicated a linear relationship. The equation of the line fitted by least squares was: $L=1.776+0.664\ S$, where L=the total length of fish (inches), and S=the anterior scale radius (mm x 42). A value of 1.8 was used as the intercept in calculations of length. This intercept was closely similar to that of 1.9 determined by Larmoyeux (1951) for drum of western Lake Erie.

Disagreements between the grouped data and the graph of the equation were small and did not exceed 0.2 inch for fish 3.2–12.7 inches long, or 0.3 inch for fish as large as 16.2 inches. At greater lengths, disagreements were larger (maximum of 1.2 inches), but the data were randomly distributed about the regression line.

TABLE 6

*Percentage of drum of age-groups I–IV with new scale growth on differnt dates**

Date of capture	Age group			
	I	II	III	IV
June 19–24	22.4 (76)	1.1 (95)	0.0 (45)	0.0 (79)
July 13–20	92.9 (14)	88.9 (36)	75.0 (40)	58.5 (94)
August 4–8	100.0 (12)	100.0 (9)	100.0 (12)	90.5 (21)

*Number of fish in parentheses.

ANNULUS FORMATION AND SEASONAL GROWTH

New growth for 1958 first appeared on scales of drum captured during June 19–24; by August 4–8, new growth was present on the scales of nearly all fish of age-groups I–IV, the only age groups for which sufficient specimens were available for detailed analysis of annulus formation (table 6). Water temperatures at the bottom in western Lake Erie in 1958 rose to 65°F near the onset of growth (June 19–24) and ranged from 72° to 75°F by August 1–10, when nearly all fish had formed annuli. Butler and Smith (1950) stated that annulus formation on the scales of drum in the upper Mississippi River navigation pools began in early or mid-May and extended to mid-July, but gave no data on water temperature.

Younger drum started growth earlier than older fish (table 6), a characteristic common among many species (Bailey, 1964; Hile, 1941; McFadden, 1959; Smith, 1956; Warner and Fenderson, 1963). New growth was present on the scales of 22.4% of age-group I, 1.1% of age-group II, and none of age-groups III and IV captured June 19–24. By July 13–20, most fish of age-groups I–IV had new growth, and the percentage of those with new growth continued to be greater in the younger age groups (92.9%, 88.9%, 75.0%, and 58.5% of age-groups I–IV, respectively). Scales of all fish in age-groups I–III and 90.5% of those in age-group IV had new growth by August 4–8.

The relationship between fish length and the time of annulus formation was less well defined, but the larger fish of an age group appeared to begin growth earlier than the smaller fish. Drum in age-groups I–III with new growth on their scales clearly were longer than "nongrowing" fish at the start of the 1958 growing season (table 7). In age-group IV, however, the average lengths of growing and nongrowing fish were identical, even though those with new growth had greater average lengths at the start of the growing season in four of the six catches that were combined in table 7.

Progress of the season's growth in age-groups O–IV (table 8) was remarkably regular. Growth increments increased consistently until early October and changed little thereafter. The length at capture of age-group O fish increased in each period except October 22–27, when the length was 0.1 inch less than October 2–9. The small changes in length during October suggest that growth was completed or near completion by the end of October. The total seasonal growth of age-groups O–IV in 1958 was respectively 4.1, 2.6, 1.5, 1.0, and 0.8 inches.

TABLE 7

*Relation between length of fish and time of onset of growth**

Age and scale growth	Number of fish	Fish length (inches) before start of growth
Age-group I		
Growing	24	4.8
Nongrowing	56	4.6
Age-group II		
Growing	20	7.6
Nongrowing	16	7.4
Age-group III		
Growing	29	9.7
Nongrowing	10	9.4
Age-group IV		
Growing	55	10.9
Nongrowing	35	10.9

*All catches made between June 19 and July 20, 1958; only catches containing both "growing" and "nongrowing" fish were used. Length for nongrowing fish is length at capture; length for growing fish is calculated length at outermost annulus.

Curves fitted by inspection (fig. 2) to the data of table 8 formed the basis for estimates of percentage of the full season's growth completed by each of the age groups during semimonthly periods (table 9). These data show that older age groups completed their period of rapid growth sooner than the younger groups. The greatest growth during a semimonthly period by age-groups II (29.6%), III (33.7%) and IV (32.0%) was made during August 1–15. The maximum growth of fish in age-group I (30.8%) was during August 16–30. No data are available for age-group O from hatching (late June to mid-July) through early August. The most rapid growth of the O-group, however, appears to have been during August. Despite the earlier start of growth in younger age groups (table 6), by July 1–15 age-groups I–IV had each completed a similar portion of total season's growth (12.6–15.9%). At the end of the next period (July 16–31), however, the older age groups generally had completed a greater percentage of the season's growth (23.8, 34.5, 44.2, and 37.3% for age-groups I–IV, respectively). The difference among the age groups in percentage of season's growth completed decreased slightly by August 16–31 and was again small by September 1–15 (89.9–95.8% complete for all age groups).

TABLE 8

*Amount of season's growth in length completed by age groups of drum captured on various dates during the 1958 growing season**

Period	Age group				
	0	I	II	III	IV
June 19–24	——	0.05 (76)	<0.01 (95)	0.00 (45)	0.00 (79)
July 13–20	——	0.37 (14)	0.18 (36)	0.15 (40)	0.12 (94)
August 4–10	1.6 (49)	0.8 (12)	0.8 (9)	0.6 (12)	0.4 (19)
August 20–26	2.4 (306)	1.8 (25)	1.0 (49)	0.8 (37)	0.6 (48)
September 10–19	3.6 (405)	2.4 (62)	1.3 (63)	0.9 (50)	0.7 (63)
October 2–9	4.1 (379)	2.6 (38)	1.4 (31)	0.9 (27)	0.7 (20)
October 22–27	4.0 (423)	2.6 (26)	1.5 (35)	1.0 (25)	0.8 (42)

*Growth for age-groups I–IV calculated from the scales; growth data for 0-age group fish are length at capture. Number of fish in parentheses.

TABLE 9

*Percentage of season's growth completed by various age groups during semimonthly periods in 1958**

Period	Age group				
	0	I	II	III	IV
June 16–30	——	3.8 (3.8)	2.8 (2.8)	0.0 (0.0)	0.0 (0.0)
July 1–15	——	8.8 (12.6)	13.1 (15.9)	15.8 (15.8)	13.3 (13.3)
July 16–31	——	11.2 (23.8)	18.6 (34.5)	28.4 (44.2)	24.0 (37.3)
August 1–15	—— (47.8)	27.3 (51.1)	29.6‡ (64.1)	33.7‡ (77.9)	32.0‡ (69.3)
August 16–31	23.5 (71.3)	30.8‡ (81.9)	18.6 (82.7)	12.6 (90.5)	18.6 (87.9)
September 1–15	18.6 (89.9)	11.9 (93.8)	9.7 (92.4)	5.3 (95.8)	6.7 (94.6)
September 16–30	8.1 (98.0)	5.0 (98.8)	5.5 (97.9)	2.1 (97.9)	2.7 (97.3)
October 1–17	2.0 (100.0)	1.2 (100.0)	2.1 (100.0)	2.1 (100.0)	2.7 (100.0)

*Data based on the curves of figure 2; cumulative percentage of season's growth completed by end of period given in parentheses; season's growth assumed to be complete by October 17.

‡Period of greatest growth.

GROWTH IN LENGTH

Although not all fish of age-groups I–IV could be sexed, the calculated lengths for the first 4 years for age-groups I–IV (table 10) and for fish of age-groups V–XIV (table 11) suggest that males and females grew at the same rate through the 4th year of life. The calculated lengths of table 10 for males and for females are not valid estimates for these age groups (especially groups I and II), however, because they do not include the unsexed fish that had slower growth. Growth estimates for age-groups I–IV therefore were adjusted by assigning unsexed fish as males or females on the basis of the sex ratios for each age group. This assignment was justified because there was no evidence that identification was easier for males than for females and because apportionment on any other basis would have caused the adjusted growth rates of the sexes to differ in age-groups I–IV. The adjusted growth histories of age-groups I–IV are given in tables 12 and 13.

TABLE 10

Calculated total length at end of each year of life of various sex classifications of Lake Erie drum in age-groups I–IV

Age group and sex	Number of fish	Length at capture	Year of life			
			1	2	3	4
I						
Male	24	7.9	5.2	—	—	—
Female	16	7.7	5.1	—	—	—
Unknown	236	5.8	4.7	—	—	—
II						
Male	83	8.8	4.8	7.8	—	—
Female	91	8.7	4.9	7.8	—	—
Unknown	159	7.8	4.8	7.4	—	—
III						
Male	143	10.2	5.2	7.6	9.9	—
Female	94	10.5	5.4	7.8	9.9	—
Unknown	16	9.3	5.0	6.8	8.7	—
IV						
Male	202	11.3	5.2	8.0	9.8	11.0
Female	187	11.5	5.4	8.0	9.7	11.1
Unknown	2	11.6	6.0	8.5	10.2	11.4

TABLE 11

*Calculated total length (inches) of male and female drum in age-groups V–XIV at the end of each of the first 4 years of life**

Sex	Number of fish	Year of life			
		1	2	3	4
Male	148	5.4	8.5	10.8	12.1
Female	104	5.4	8.5	10.7	12.1

*Length are sums of average increments.

Two estimates of general growth, the grand average calculated length and the sum of the average increments, were obtained from the data of tables 12 and 13. Although both are valid, the grand average calculated lengths serve best to show the relation between length and age. The sum of the average increments is more descriptive of actual growth, however, especially under conditions of changing growth rate, and is used in preference to the grand average calculated lengths as an estimate of general growth in length.

Growth based on the sums of the average increments was nearly identical for males and females during the first 4 years of life (tables 12 and 13). In the 5th through the 11th years, however, the females grew more rapidly than the males and, by the end of the 11th year, females were 1.5 inches longer than males. The decrease in the difference between the two sexes to 1.3 inches in the 12th and 13th years reflects the absence of females in age-group XIII, and the slow growth of fish in age-group XIV.

TABLE 12

*Calculated total length (inches) at end of each year of life of each age group, and average growth for combined age groups of female Lake Erie drum**

Age group	Number of fish	Length at capture	Year of life													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
I	110	6.1	4.8	—	—	—	—	—	—	—	—	—	—	—	—	—
II	174	8.3	4.9	7.6	—	—	—	—	—	—	—	—	—	—	—	—
III	100	10.4	5.4	7.7	9.8	—	—	—	—	—	—	—	—	—	—	—
IV	188	11.5	5.4	8.0	9.7	11.1	—	—	—	—	—	—	—	—	—	—
V	32	13.5	5.5	8.6	10.7	12.1	13.2	—	—	—	—	—	—	—	—	—
VI	55	14.0	5.2	8.3	10.5	11.9	12.9	13.9	—	—	—	—	—	—	—	—
VII	4	16.0	5.8	8.5	10.9	12.0	13.3	14.4	15.4	—	—	—	—	—	—	—
VIII	3	17.5	5.3	9.4	12.1	13.6	14.4	15.3	16.3	17.1	—	—	—	—	—	—
IX	5	17.0	5.6	8.6	10.9	12.5	13.6	14.5	15.1	15.9	16.7	—	—	—	—	—
X	2	18.5	5.7	8.7	11.9	13.7	15.2	16.1	16.6	17.1	17.6	18.3	—	—	—	—
XII	2	20.0	6.0	7.9	11.3	13.1	14.6	15.5	16.0	16.8	17.6	18.5	19.4	19.7	—	—
XIV	1	18.9	5.6	8.3	11.2	12.4	13.2	14.2	14.7	15.9	16.4	16.8	17.2	17.6	18.1	18.9
Grand average calculated length			5.2	7.9	10.0	11.5	13.2	14.1	15.6	16.5	17.0	18.1	18.6	19.0	18.1	18.9
Increment of average			5.2	2.7	2.1	1.5	1.7	0.9	1.5	0.9	0.5	1.1	0.5	0.4	−0.9	0.8
Grand average increment of length			5.2	2.7	2.0	1.4	1.1	1.0	0.7	0.8	0.7	0.8	0.7	0.4	0.5	0.8
Sum of average increment of length			5.2	7.9	9.9	11.3	12.4	13.4	14.1	14.8	15.6	16.4	17.1	17.5	18.0	18.8

*Includes 184 fish in age-groups I–IV lacking sex data, that were assigned as females.

TABLE 13

*Calculated total length (inches) at end of each year of life of each age group, and average growth for combined age groups of male Lake Erie drum**

Age group	Number of fish	Length at capture	Year of life												
			1	2	3	4	5	6	7	8	9	10	11	12	13
I	166	6.1	4.8	—	—	—	—	—	—	—	—	—	—	—	—
II	159	8.3	4.8	7.6	—	—	—	—	—	—	—	—	—	—	—
III	153	10.1	5.2	7.6	9.8	—	—	—	—	—	—	—	—	—	—
IV	203	11.3	5.2	8.0	9.8	11.0	—	—	—	—	—	—	—	—	—
V	45	12.6	5.3	8.2	10.4	11.7	12.4	—	—	—	—	—	—	—	—
VI	52	13.4	5.3	8.3	10.5	11.7	12.5	13.1	—	—	—	—	—	—	—
VII	14	15.0	5.5	9.0	11.4	12.7	13.5	14.3	14.7	—	—	—	—	—	—
VIII	9	15.0	5.5	8.9	11.0	12.5	13.4	14.0	14.5	14.8	—	—	—	—	—
IX	8	15.8	5.1	8.7	10.9	12.3	13.2	13.8	14.6	15.0	15.5	—	—	—	—
X	7	17.6	5.9	9.3	12.1	13.5	14.4	15.2	15.6	16.2	16.8	17.3	—	—	—
XI	3	17.8	5.7	8.3	10.4	12.2	13.3	14.2	15.1	16.0	16.7	17.3	17.6	—	—
XII	5	18.6	6.0	9.2	11.2	12.8	13.6	14.4	15.2	16.0	16.7	17.2	17.7	18.3	—
XIII	5	18.4	5.1	7.7	10.5	12.0	13.5	14.2	14.9	15.6	16.2	16.7	17.3	17.8	18.3
Grand average calculated length			5.1	7.9	10.1	11.4	12.8	13.7	14.9	15.5	16.3	17.1	17.5	18.0	18.3
Increment of average			5.1	2.8	2.2	1.3	1.4	0.9	1.2	0.6	0.8	0.8	0.4	0.5	0.3
Grand average increment of length			5.1	2.8	2.1	1.3	0.8	0.7	0.6	0.6	0.6	0.5	0.5	0.6	0.5
Sum of average increment of length			5.1	7.9	10.0	11.3	12.1	12.8	13.4	14.0	14.6	15.1	15.6	16.2	16.7

*Includes 229 fish in age-groups I–IV lacking sex data, that were assigned as males.

The 1st-year growth of 5.1–5.2 inches was much greater than the growth in any of the following years of life, as is common among fish. Increments decreased sharply in the 2nd through the 5th years, but changed only slightly thereafter; beyond the 6th year, the value varied little for males (0.5 or 0.6 inch) and ranged from 0.4 to 0.8 inch for females. Because of slow growth in the later years of life, attainment of large size required survival to an advanced age. Males reached 12 inches in 5 years, 15 inches in 10 years, and nearly 17 inches at 13 years. Females reached 12 inches in about 5 years, 15 inches in about 8 years, and exceeded 18 inches at 14 years.

COMPARISON OF GROWTH IN LAKE ERIE AND OTHER WATERS

Average growth of drum collected in Lake Erie in 1958 was slower than that reported by Van Oosten (1938) for fish taken in 1927 (table 14). The length advantage of drum taken in 1927 was established principally in the 1st year of life, although growth in the 2nd through the 8th years was also slightly greater than in 1958. In comparison to these 1958 data, drum in 1927 averaged 0.6–0.7 inch larger at the end of the 1st year of life, were 12 inches long 1 year earlier, and were 17 inches 1 to 2 years earlier.

TABLE 14

*Length (inches) of drum at the end of different years of life in Lake Erie and in certain other waters**

Area and study	Year of life									
	1	2	3	4	5	6	7	8	9	10
Lake Erie										
Present study										
Male	5.1	7.9	10.1	11.4	12.8	13.7	14.9	15.5	16.3	17.1
Female	5.2	7.9	10.0	11.5	13.2	14.1	15.6	16.5	17.0	18.1
Van Oosten (1938)†	5.8	8.7	10.8	12.4	13.7	15.1	16.0	17.0	——	——
Upper Mississippi River‡ (Butler and Smith, 1950)	4.9	9.0	11.7	13.4	14.8	16.5	18.1	19.1	——	——
Oklahoma waters§ (Houser, 1931)										
Rock Creek	3.0	5.1	6.7	8.3	9.6	9.9	——	——	——	——
Altus City Lake	6.1	11.5	17.7	20.5	22.6	26.0	27.4	28.8	30.0	31.0

*Growth estimates are given as grand average calculated lengths, because sums of average increments of length were not available for all stocks shown here.

†Standard length in millimeters calculated by direct proportion (body-scale ratio assumed constant) were converted to total length in inches and recalculated on the basis of the body-scale relationship determined in the present study. Sex not determined.

‡Lengths calculated by empirically determined body-scale relationship (intercept 0.8 inch). Authors found no difference in the growth rate of males and females.

§Lengths were calculated by direct proportion assuming a constant body-scale ratio. Sex not determined.

Lake Erie drum captured in 1958 grew more slowly than drum from the upper Mississippi River (Butler and Smith, 1950; table 14). First-year growth of drum in the upper Mississippi River was less than in Lake Erie, but rapid growth in the 2nd and later years enabled them to reach 17 inches in the 7th year—2 to 3 years earlier than the Lake Erie fish. Lake Erie fish grew considerably slower than drum in Altus City Lake, Oklahoma (Houser, 1960), the stock with the fastest recorded growth rate. Growth in the 1st year of life was only slightly better in Altus City Lake but, after the 2nd year, it was more than twice that in Lake Erie. Lake Erie drum, however, grew more rapidly than Rock Creek drum—the stock with the slowest recorded growth (Houser, 1960). First-year growth in Rock Creek was slow (3 inches) and, although growth improved there in the 2nd and later years of life, drum remained 2.8 to 3.8 inches shorter in Rock Creek than in Lake Erie.

Lake Erie is a moderately favorable environment for growth of drum during the 1st year, but the requirements for sustained good growth in the 2nd and later years of life are met less well, and the advantage of good growth in the first year is soon lost. Thus the growth rate of drum in Lake Erie generally falls below the midpoint of the range of growth in other waters (table 14).

ANNUAL FLUCTUATIONS OF GROWTH IN LENGTH AND THE GROWTH-TEMPERATURE RELATION

The percentage fluctuation of annual growth in length of males and females combined for 1951–57 (table 15) showed less variability in the 1st year than in the 2nd and later years of life. First-year growth declined 17.1% in 1951–57. Growth in the 2nd and later years declined 40.7% in 1951–56, but improved markedly in 1957 (8.0%). The wider fluctuations of growth after the 1st year suggests that the factors contributing to fluctuations operate more strongly after the 1st year of life.

TABLE 15

*Percentage deviation of growth in length in various calendar years from the 1951–57 average**

Deviation in year of life	Calendar year						
	1951	1952	1953	1954	1955	1956	1957
1st year	8.5	1.2	3.1	1.2	1.2	− 6.6	−8.6
2nd and later years	24.4	4.4	4.4	−4.6	−4.6	−16.3	−8.0

*Sexes combined on an unweighted basis.

TABLE 16

*Air and water temperatures (°F) in western Lake Erie, May-October 1958**

Month	Air	Water	
		Surface	Bottom
May	59.6	57.1	55.3
June	65.2	66.4	65.0
July	73.6	75.6	70.1
August	71.4	75.2	71.6
September	65.8	67.1	66.9
October	56.0	58.4	58.2

*Air temperatures are monthly means from the published records of the U.S. weather station at Sandusky, Ohio. Water temperatures are from fishing stations in western Lake Erie and are averages for 10 to 19 observations made during each month.

The relation between growth and temperature in 1951–57 was tested by calculating coefficients of correlation between annual fluctuations in growth and monthly mean air temperatures recorded at the U.S. weather station at Sandusky, Ohio. These air temperatures showed good agreement with surface- and bottom-water temperatures in western Lake Erie (table 16).

All 63 possible combinations of monthly air temperature for May through October were tested for correlation with growth in the 1st, and in 2nd and later years of life. Growth in the 1st year was not significantly corrected with air temperature in any of the individual months during the growing season (June through October), or with May temperatures, which might influence the early seasonal growth. The combined temperatures for the period May through October also were not correlated with growth in the 1st year of life. Elimination of August and September, however, provided a 4-month combination that gave a good ($p = 0.05$) correlation with growth in the 1st year of life (table 17). Combined temperatures for May, June, July, September, and October; for June, July, and October; and also for May, June, September, and October were correlated with the 1st-year growth at the $p = 0.10$ level. Growth after the 1st year was not significantly correlated with temperature.

Although the general relation for poikilotherms is for metabolic rate to increase with an increase in temperature, it has been demonstrated clearly by Kinne (1960) that there is probably a temperature range over which fish grow most rapidly, and that temperatures above and below this range operate directly on metabolism to cause growth to decrease or stop. During the growth period, temperatures below the optimum would be expected to be correlated positively with growth; negative correlations should be found for temperatures higher than optimum, and temperatures within the optimum range should give no correlation. The correlations for Lake Erie drum indicate that growth in the 1st year of life is independent of temperature during August, and to some extent in September, but is augmented by high temperatures in May-July and in October (table 17). It appears, therefore, that temperatures in Lake Erie usually are near the optimum for 1st-year growth during August and are less than optimum during other months of the growing season. This conclusion is supported by information on seasonal changes in the growth rate of young-of-the-year drum in 1958 (fig. 2). The growth curve for O-group drum, although incomplete, strongly suggests that growth was most rapid during August, when bottom water temperatures were highest (table 16).

TABLE 17

*Coefficients of correlation between 1st-year growth and various combinations of average monthly air temperatures for 1951–57**

Months	Coefficient of correlation
May, June, July, and October	0.754
May, June, July, September, and October	0.717
June, July, and October	0.708
May, June, September, and October	0.671

*Only combinations correlating at the 10% level or higher are given (no correlations at the 10% level or higher were found for growth in the 2nd and later years of life). For 5 degrees of freedom $r = .754$ at the 5% level; at the 10% level $r = .669$.

The effect of temperature on growth in the 2nd and later years of life is not clear. Although temperature and growth after the 1st year were not significantly correlated, some conformity with the growth-temperature relation shown for 1st-year growth is suggested by a similar trend in annual fluctuations of growth in the 1st, and in second and later years (table 15). Growth in the 2nd and later years of life, as in the 1st year, was most rapid in August (table 9), when temperatures were highest (table 16), and was slower at other times in the growing season, when temperatures were lower. The failure of growth to show the same correlations with temperature in the 2nd and later years as it did in the 1st-year suggests, however, that the growth-temperature relation of the older drum may be obscured by factors related to age or size.

TABLE 18

*Length-weight relationship of Lake Erie drum**

Number of fish	Average total length (inches)	Average weight (ounces)	
		Empirical	Calculated
5	3.2	0.2	0.2
10	3.7	0.3	0.3
36	4.2	0.5	0.4
27	4.7	0.6	0.6
23	5.2	0.9	0.9
22	5.7	1.1	1.2
31	6.2	1.5	1.5
44	6.7	1.9	2.0
75	7.2	2.4	2.5
107	7.7	2.9	3.0
85	8.2	3.7	3.7
76	8.7	4.4	4.5
75	9.2	5.3	5.3
88	9.7	6.2	6.3
91	10.2	7.2	7.4
136	10.7	8.5	8.6
130	11.2	9.8	9.9
111	11.7	11.2	11.4
67	12.2	12.8	13.1
60	12.7	15.0	14.8
50	13.2	17.2	16.7
42	13.6	19.4	18.4
23	14.2	22.6	21.1
20	14.7	24.7	23.5
16	15.2	26.4	26.1
12	15.7	30.0	28.9
8	16.2	35.3	32.0
5	16.6	33.0	34.5
6	17.2	42.8	38.6
7	17.7	40.0	42.3
5	18.3	48.8	47.0
7	18.7	48.9	50.3
2	19.2	50.5	54.7
1	19.8	62.0	60.3
1	20.1	52.0	63.2
1	22.4	98.0	89.0

*The lengths are true averages for fish in 0.5-inch groups.

LENGTH-WEIGHT RELATION AND GROWTH IN WEIGHT

Differences in weight between the sexes and between mature and immature drum of the same length were so small that an estimate of the general length-weight relation could be obtained from a combination of data for all fish. The equation for length-weight relation determined by a least squares fit of the logarithms of the lengths and weights (table 18) was:

$$\text{Log } W = -2.3192 + 3.1615 \log L,$$

where W = weight in ounces,
and L = total length in inches.

The agreement between calculated and empirical weights was generally close (table 18). Discrepancies were randomly distributed, and were small at lengths less than 16.2 inches. Disagreements were greater among data for the larger fish, but did not exceed 4.2 ounces for fish 16.2 to 19.2 inches long.

TABLE 19

Calculated weight (ounces) at the end of each year of life*

Year of life	Male		Female	
	Calculated weight	Increment	Calculated weight	Increment
1	0.8	0.8	0.9	0.9
2	3.3	2.5	3.3	2.4
3	7.0	3.7	6.7	3.4
4	10.2	3.2	10.2	3.5
5	12.7	2.5	13.7	3.5
6	15.2	2.5	17.5	3.8
7	17.5	2.3	20.6	3.1
8	20.2	2.7	24.0	3.4
9	23.0	2.8	28.4	4.4
10	25.6	2.6	33.2	4.8
11	28.4	2.8	37.9	4.7
12	32.0	3.6	40.8	2.9
13	35.2	3.2	44.6	3.8
14	——	——	51.2	6.6

*Weights were computed from the general length-weight equation and the average increments of length of tables 13 and 14.

TABLE 20

Sex composition of drum in Lake Erie, 1958

Age group	Number of females	Number of males	Percentage males
I	16	24	60
II	91	83	48
III	94	143	60
IV	187	202	52
V	32	45	58
VI	55	52	49
VII	4	14	78
VIII	3	9	75
IX	5	8	62
X	2	7	78
XI	——	3	100
XII	2	5	71
XIII	——	5	100
XIV	1	——	0
Total	492	600	55

Growth in weight (table 19) was determined from the general length-weight equation and the sums of average increments of length shown in tables 12 and 13. The annual increments of weight were similar for the sexes in the 1st 4 years of life, but thereafter (except in the 12th year) the increments of the females were substantially larger. First-year increments of males and females were 0.8 and 0.9 ounce, respectively. Increments increased sharply after the 2nd year, and were 3.2–3.7 ounces in the 3rd and 4th years. The increment of the males decreased to 2.5 ounces in the 5th and 6th years and was even lower (2.3 ounces) in the 7th year, but thereafter showed a general increase. The annual increments in weights of females also showed a general increase with age, but fluctuated more widely than did those of the males.

Growth in weight was slow; both males and females required nearly 4 years to reach 10 ounces. After the 4th year of life, females gained weight more rapidly than the males. Females averaged 1 pound in the 6th year and 2 pounds in the 10th. Males did not weigh 1 pound until the 7th year and required 12 years to reach 2 pounds.

TABLE 21

*Relation between length and maturity**

Length interval	Male			Female		
	Immature	Mature	Percentage mature	Immature	Mature	Percentage mature
7.0– 7.4	44	1	2	44	—	0
7.5– 7.9	40	2	5	58	—	0
8.0– 8.4	43	2	4	23	—	0
8.5– 8.9	20	5	20	24	—	0
9.0– 9.4	25	14	36	28	1	3
9.5– 9.9	41	17	29	34	5	13
10.0–10.4	21	37	64	34	3	8
10.5–10.9	18	50	74	55	10	15
11.0–11.4	15	55	79	47	6	11
11.5–11.9	4	39	91	32	4	11
12.0–12.4	4	28	88	17	5	23
12.5–12.9	—	18	100	10	8	44
13.0–13.4	—	28	100	9	11	55
13.5–13.9	—	10	100	5	13	72
14.0–14.4	—	9	100	4	8	67
14.5–14.9	—	10	100	3	4	57
15.0–15.4	—	10	100	2	4	67
15.9–15.9	—	4	100	1	2	67

*Immature fish include a number of individuals of undetermined sex that were assigned as males or females on the basis of the sex ratio of fish in each 0.5-inch interval. All fish shorter than 7.0 inches were immature; all longer than 15.9 inches were mature.

SEX RATIO, MATURITY, AND SPAWNING

Males were more abundant than females in 11 of 14 age groups (table 20). In age-groups I–VI, 54% were males, but the ratio in age-groups VII and older increased to 75% males. The number of fish in age-groups VII and older was small, however, and the sex ratio for all 14 age groups was 55% males.

Drum reached maturity between 7.0 and 15.9 inches; males matured at smaller sizes than females (table 21). The smallest mature male was in the 7.0–7.4-inch interval; 64% of the males were mature at 10.0–10.4 inches, and 100% were mature above 12.4 inches. The smallest mature female was in the 9.0–9.4-inch-length interval; 55% were mature at 13.0–13.4 inches, and all females longer than 15.9 inches were mature. First maturity and 100% maturity of males occurred at lengths respectively 2.0 and 3.5 inches shorter than for females.

Males mature at an earlier age than females (table 22). The youngest mature males were in age-group II and all in age-groups VI and older were mature. First maturity and 100% maturity in females were reached in age-groups III and VII, respectively. The percentage of mature females in each of age-groups III–VI was consistently smaller than that of mature males in the same age group.

Ages at maturity reported by Daiber (1953) for 174 Lake Erie drum captured in the spring of 1948 were greater than those of this study. First maturity occurred among males in age-group IV and 100% maturity was reached in age-group VII; females matured first in age-group V and were 100% mature in age-group IX. Because of possible problems related to differences in growth rate, gear selectivity, and segregation within stocks, it is uncertain whether there is a true difference between the two periods in age at maturity. The samples of the present study, however, provide a sound basis for an estimate of the relation between age and maturity in 1958, because they were taken throughout the entire western basin of Lake Erie and include catches during the spawning season, when the state of sexual development is most easily determined.

TABLE 22

*Relation between age and sexual maturity of Lake Erie drum**

Age group	Percentage mature	
	Males	Females
II	3 (159)	0 (174)
III	38 (153)	7 (100)
IV	77 (203)	13 (188)
V	91 (45)	50 (32)
VI	100 (52)	65 (55)

*Number of fish in parentheses. All fish in age-group I were immature and all older than VI were mature.

TABLE 23

*State of maturity of drum at various times during the spawning period in 1958**

Dates	Percentage of mature males			Percentage of mature females		
	Unripe	Ripe	Spent	Unripe	Ripe	Spent
April 25–May 8	86 (6)	14 (1)	—	100 (3)	—	—
May 17–June 2	100 (18)	—	—	100 (8)	—	—
June 19–24	52 (33)	48 (30)	—	33 (5)	67 (10)	—
July 13–20	13 (12)	20 (18)	66 (59)	—	23 (8)	77 (27)
August 4–8	—	—	100 (17)	—	—	100 (3)

*Number of fish in parentheses.

The spawning season of drum in western Lake Erie in 1958 fell between June 24 and August 4 and may have reached a peak in early July (table 23). A single ripe male was captured during April 25-May 8, but no others were taken until mid-June. During June 19–24, 48% of the mature males were ripe. Spent males first appeared on July 13–20, when they made up 66% of the mature fish. No ripe or freshly spent males were captured after July 20. The first ripe females were taken June 19–24 and made up 67% of the mature females. Spawning had passed its peak by July 14–20, when 23% of the females were ripe and 77% were spent. All mature females taken after July 20 were spent.

ACKNOWLEDGMENTS

The author wishes to thank Drs. Stanford H. Smith, Ralph Hile, and Paul H. Eschmeyer of the Bureau of Commercial Fisheries Biological Laboratory, Ann Arbor, Michigan, for their critical review of the manuscript.

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Reprinted from Radiation Research, Volume 32, No. 4, December 1967
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RADIATION RESEARCH **32,** 685–691 (1967)

Effect of Single and Continuous Exposures of Gamma Radiation on the Survival and Growth of the Blue Crab, *Callinectes sapidus*

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ENGEL, DAVID W. Effect of Single and Continuous Exposures of Gamma Radiation on the Survival and Growth of the Blue Crab, *Callinectes sapidus*. *Radiation Res.* **32,** 685–691 (1967).

The survival and growth of young blue crabs, *Callinectes sapidus*, were observed after single and continuous exposures to gamma radiation. In the single-exposure experiment, crabs were given doses of 4, 8, 16, 32, or 64 × 10^3 rads; crabs exposed to continuous irradiation received 3.2, 7.3, or 29.0 rads/hr. The $LD_{50(30)}$ value for the crabs receiving single exposures was estimated at 51,000 rads. Behavioral changes following irradiation, characterized by a loss of coordination, also appeared in these crabs. The intensity of the behavioral change decreased with decreasing radiation dose. In the continuous-irradiation experiments, survival and growth were reduced only in the crabs exposed to the highest radiation dose rate of 29.0 rads/hr. Crabs receiving the lowest radiation dose rate of 3.2 rads/hr grew at a greater rate than crabs in the other two irradiated groups and in the control group.

INTRODUCTION

Concern has existed for years over possible effects of continuous low-level irradiation from environmental concentrations of radionuclides on the growth, survival, and reproduction of aquatic organisms. Investigations of the effects of radiation on marine and freshwater invertebrates have concerned fiddler crabs and grass shrimp (*1*), sea urchins and mud snails (*2*), oysters and clams (*3*), freshwater snails (*4*), and adult brine shrimp (*5*). Marshall (*6*) determined the effects of chronic irradiation on the survival and intrinsic population growth of *Daphnia*.

The experiments discussed in this paper were designed to determine the effects of single and continuous exposures to gamma radiation on the survival and growth of young blue crabs, *Callinectes sapidus*.

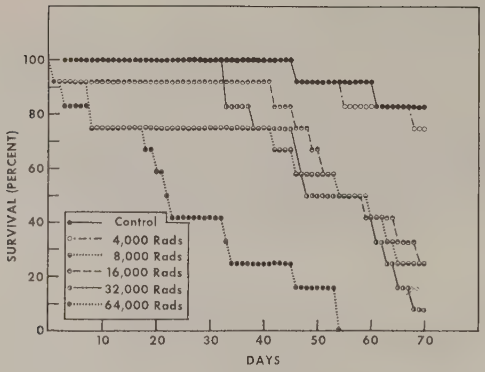

FIG. 1. Survival of blue crabs which received different doses of gamma radiation.

MATERIALS AND METHODS

Young-of-the-year blue crabs 10 to 15 mm in carapace width were collected in the Beaufort estuary and acclimated to laboratory conditions for 1 week before initiation of the experiments. The crabs were maintained in 30‰ sea water in individual polystyrene containers 10 cm in diameter and 6.5 cm deep at 20°C. The water was changed and the crabs were fed three times a week.

In the single-exposure experiments, groups of 12 crabs were irradiated with doses of 4000, 8000, 16,000, 32,000, or 64,000 rads in a self-contained 1500-Ci ^{60}Co irradiator at a dose rate of 365 rads/min (±10%). Constant aeration was provided during irradiation. Controls were treated in a similar manner but were not irradiated.

In the continuous-irradiation experiment, three groups of 20 crabs were placed in concentric circles at distances of 0.5, 1.0, and 1.5 meters from a 10-Ci ^{60}Co point source and were irradiated an average of 22.5 hr/day at rates of 3.2, 7.3, or 29.0 rads/hr. The total radiation doses received over 70 days by the three groups of crabs were 5,105, 11,502, and 45,693 rads. Control crabs were maintained under similar conditions in an adjacent room. Survival, frequency of molting, and width of the molted carapace were directed for irradiated and control crabs. The criteria used to determine crab death were drooping of the maxillipeds, cessation of gill bailer movements, and lack of response from the antennae when stimulated.

EFFECTS OF SINGLE EXPOSURES

The sensitivity of blue crabs to radiation was similar to that observed for other marine invertebrates: All crabs irradiated with 64,000 rads died, whereas the survival of other groups increased as radiation dose decreased (Fig. 1). Crabs that received 8000 rads had two early deaths that may have been caused by injury during the irradiation procedure. The LD$_{50}$'s at different times after irradiation

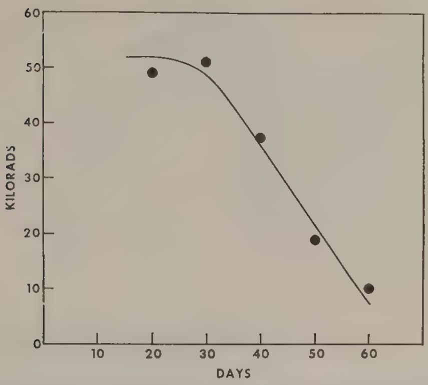

FIG. 2. LD_{50} values for blue crabs at different times after irradiation.

were estimated by the method of Reed and Muench (*7*). The relationship between time after irradiation and LD_{50} is linear from 30 through 60 days (Fig. 2). The $LD_{50(30)}$ value for the blue crab is 51,000 rads, which is considerably higher than the $LD_{50(30)}$ values reported for two other species of decapods—*Uca pugnax*, 8000 R, and *Palaemonetes pugio*, 1500 R (*1*). These differences in sensitivity to radiation may be attributable to a factor such as salinity, temperature, or irradiation dose rate. The blue crab $LD_{50(30)}$ value was within the range for three marine invertebrates—*Arbacia punctulata*, 38,900 R; *Nassarius obsoletus*, 37,500 R; and *Urosalpinx cinerea*, 44,000 R—but was lower than the range for two others—*Mercenaria mercenaria*, 110,000 R; and *Crassostrea virginica*, 110,000 to 140,000 R (*2*).

Blue crabs are voracious and pugnacious in nature so that the events leading up to death are quite striking. First the crab quits eating and shows loss of its characteristic antagonism. In one or two days the crab's movements become sluggish and uncoordinated, and its condition rapidly degenerates until the crab appears dead. The only signs of life are the pumping of the gill bailers and movements of the antennae. In such a condition the crab may survive for 1 or 2 days.

Immediately after irradiation, all irradiated animals showed changes in behavior which may have been caused by neurological damage. Crabs that received 64,000 rads lost their equilibrium and appeared to be in a catatonic state with chelii open and all appendages rigid. Except for the pumping action of the gills and slight movement of the antennae, the crabs appeared to be dead. The extent of behavioral change decreased with decreasing radiation levels. Within 4 days irradiated crabs other than those that received 64,000 rads had regained normal irritability and were able to feed. The group that received the highest dose recovered only slightly before death. The acute "neurological" response of the irradiated blue crabs was much different from the responses of white mice, which became hyperactive and reacted intensely to external stimuli (D. W. Engel, unpublished data).

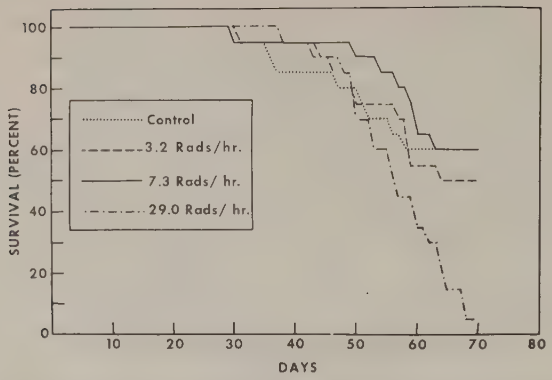

FIG. 3. Survival of control blue crabs and crabs that were subjected to continuous irradiation.

TABLE I

NUMBER OF CRAB DEATHS AND PERCENTAGE OF DEATHS WHICH OCCURRED IN MOLTING OR FOLLOWING MOLTING

Radiation dose rate	*Total number of deaths*	*Percentage of deaths in molting*
Control	8	25.0
3.2 rads/hr	10	70.0
7.3 rads/hr	8	50.0
29.0 rads/hr	19	10.5

EFFECTS OF CONTINUOUS EXPOSURE

Survival was greatly affected by radiation only in the crabs that received the highest radiation dose (Fig. 3). No irradiated or control crabs died during the first 30 days, but from the thirtieth through the seventieth day deaths occurred in all groups, and crabs receiving 29.0 rads/hr had the greatest mortality. From the fiftieth day until the end of the experiment, the crabs receiving 29.0 rads/hr ceased feeding. The accumulated radiation dose at that time was approaching the $LD_{50(50)}$ value for acutely irradiated crabs. These crabs also showed a decrease in irritability, but the decrease was not as pronounced as for the crabs that received single radiation exposures. The survival of the crabs that received 3.2 or 7.3 rads/hr was the same as that of the controls.

Unsuccessful molting apparently caused death of crabs during the experiment. The greatest percentage of total deaths that was attributed to unsuccessful molting was at the lower dose rates, where molting activity was the greatest (Table I). A substantial percentage of the deaths of control crabs also was attributed to un-

TABLE II

Percentage of Successful Molts in Irradiated and Unirradiated Crabs

Molt	*Control*	*Radiation dose rate (rads/hr)*		
		3.2	7.3	29.0
First	100	100	100	100
Second	65	75	85	55
Third	20	30	45	0

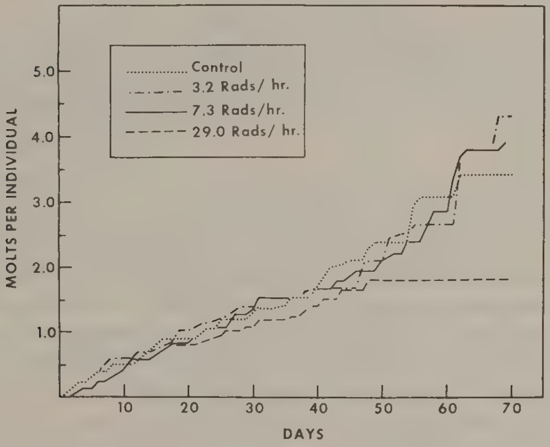

Fig. 4. Molting of control crabs and crabs that were subjected to continuous irradiation.

successful molting. The manipulation of the crabs during the experiment may have contributed to the mortality during molting.

All irradiated and control crabs molted at least once, and the numbers of second and third molts were affected by the radiation dose (Table II). The crabs that were irradiated at 29.0 rads/hr molted least, and none had three successful molts. Crabs that received 3.2 and 7.3 rads/hr underwent more second and third molts than did the controls, although this difference was not significant.

The total number of molts was affected by radiation only in the crabs that were maintained at the highest dose rate (Fig. 4). For the first 48 days, irradiated crabs of all groups and control crabs molted at about the same rate. From the forty-eighth day until the end of the experiment, crabs receiving 29.0 rads/hr did not molt. Molting in the groups at the two lower radiation levels, 3.2 and 7.3 rads/hr, was not different from that of the control crabs throughout the experiment. Molting stopped among the crabs receiving 29.0 rads/hr coincident with the increased mortality (50 days). The cessation in molting may have resulted from a buildup of

TABLE III

Mean Percentage Increase in Carapace Width for Irradiated and Unirradiated Blue Crabs

Item	*Control*	*Radiation dose rate (rads/hr)*		
		3.2	*7.3*	*29.0*
Percentage increase	15.51	18.37	14.17	13.60
Standard error	±.93	±1.37	±.28	±1.30
Number	23	24	25	14

radiation damage to a critical level which affected the normal physiological and biochemical functions involved in molting. Intermolt time did not differ significantly between irradiated and control crabs, even though 29.0 rads/hr caused a cessation in molting.

Crabs exposed at the lowest radiation dose rate had a significantly more rapid growth than the other irradiated or control crabs. Since molting is associated with growth, the percentage increase in width of molted carapaces was followed; it was found to be related to the radiation dose rate (Table III). Crabs receiving 29.0 rads/hr, the highest dose rate, had the smallest percentage increase in carapace width, and those that received 3.2 rads/hr had the largest increase in width. The mean percentage increase in carapace width for crabs exposed to 3.2 rads/hr was greater than the means of the other two irradiated groups at the 1% level and greater than the mean for controls at the 5% level. The increased growth observed at the lowest dose rate gives support to the statement of Brunst (*8*) that recognition should be given to the phenomenon of radiation stimulation, whether the stimulation is a primary or secondary effect of the radiation.

The results of these experiments should serve as a foundation for the better understanding of the effects of single and continuous exposures to gamma radiation on marine and estuarine species. The sensitivity of blue crabs to single doses of gamma radiation is similar to that of some other marine invertebrates. Continuous irradiation decreased growth and survival only at the highest dose rate, whereas the lowest dose rate enhanced crab growth. Before this information can be extended to other members of the ecosystem, more data must be collected on the effects of environmental factors and radiation on the various life stages of these organisms, and on the long-term effects on reproductive potential, life span, and genetic pool.

SUMMARY

Young-of-the-year blue crabs (*Callinectes sapidus*) were exposed to single and continuous exposures of gamma radiation to determine effects on growth and survival. The single exposures were used to determine median lethal doses at specific

times after irradiation, whereas the continuous-irradiation experiment was designed to demonstrate effects of long-term irradiation on growth and survival. The $LD_{50\ (30)}$ at 20°C was estimated at 51,000 rads, which was similar to LD_{50}'s of other invertebrates. The single exposures caused behavioral changes in all irradiated crabs, and the intensity of the response was dose-dependent. Chronic irradiation caused a decrease in survival in irradiated crabs only at the highest dose rate. Growth measured by percentage increase in carapace width was improved significantly by the lowest dose rate.

ACKNOWLEDGMENTS

I thank Mr. George H. Rees for supplying the crabs used in these experiments, and Mrs. Edna M. Davis and Mr. Curtis W. Lewis for their technical assistance. This research was supported through a cooperative agreement between the U.S. Fish and Wildlife Service and the U.S. Atomic Energy Commission.

Received: January 10, 1967

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THE SURF CLAM — NEW JERSEY'S MOST VALUABLE SEAFOOD RESOURCE

JAMES B. ENGLE AND ARTHUR S. MERRILL*

It is not unusual to find windrows of large clams along the ocean beaches of New Jersey, after an easterly storm. These are surf clams, scientifically known as *Spisula solidissima.* Some fishermen call them skimmer, bar, hen, giant, beach, or sea clams. They live in the ocean bottom from the shoreline to a depth of about 250 feet. They range from Nova Scotia to Cape Hatteras, and are concentrated off the New Jersey coast where they support a commercial fishery. A smaller variety occurs from Cape Hatteras south to the Gulf of Mexico, but this clam is not commercially important. The surf clam is relatively "new" as a seafood, but fossil shell deposits show that this clam is more than 10 million years old.

Surf clams play a significant role in the national shellfish economy. They are an important seafood for human consumption. The industry has grown from a small bait fishery in 1945 to a major fishery producing 44 million pounds of meats annually — about 80 percent of all clam meat produced. A modest bait fishery lands about 1 million pounds of smaller surf clams annually.

The production figures become more significant to New Jersey when we consider that 42 million pounds of surf clams are fished from a relatively small area of the ocean bottom off Barnegat Lightship. Of greater economic interest is the landed value of the surf clam harvest. Commercial landings have a dockside value of 3.7 million dollars annually, which makes surf clams the most valuable New Jersey seafood product. Other important New Jersey seafood resources are: menhaden, valued at 1.3 million dollars; sea scallops, 1.1 million dollars; and hard clams, 0.9 million dollars.

Desirable characteristics of the surf clam to the industry are the large size of the clam and its abundance. Eight inches approaches the maximum length, but the industry harvests clams in the size range of 5 to 6 inches. Nature has cooperated by accumulating clams of this size in extensive beds. Clams on some beds are of mixed sizes including many smaller clams; these beds are avoided by the clam dredgers. When the clam boats wander onto this kind of bed, the catch is often returned to the sea and the boats seek the places where the larger clams are concentrated.

Most surf clam vessels are modifications of shrimp trawlers, scallop boats, draggers, oyster dredgers, and surplus military craft; most are 60 to 100 feet long. The principal characteristic is a large deck to hold pumps and dredging machinery, and to store the catch. These vessels, designed for 1-day trips, have home ports at Point Pleasant, Wildwood, and Cape May, New Jersey. The vessels leave port before daylight and often do not return until evening, 14 hours later. The men that man these ships are mostly seasoned sailors, for the work is demanding — their

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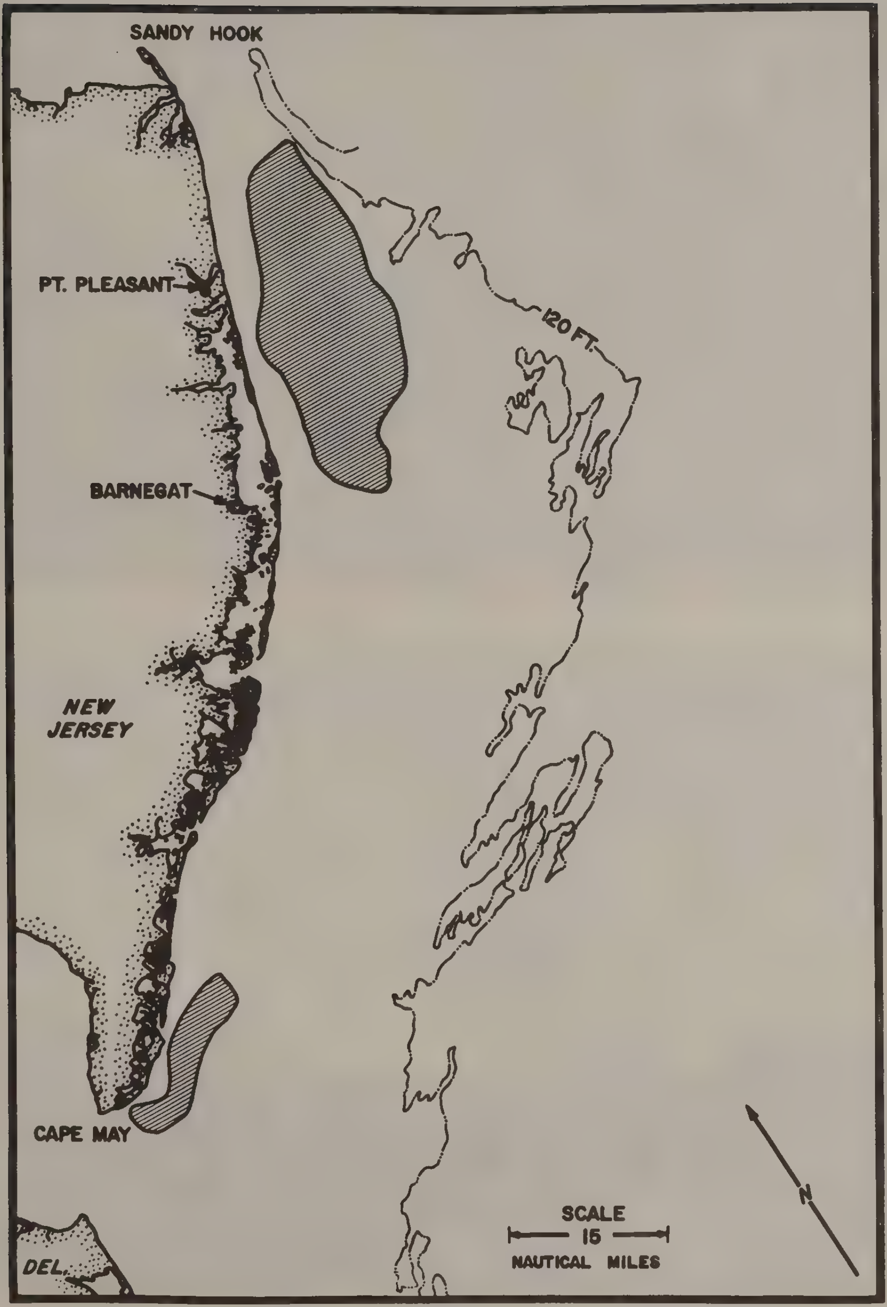
The surf clam, *Spisula solidissima* — the largest bivalve mollusk found on the Atlantic Coast, and furnishes about 5 percent of the annual shellfish landed in the United States.

compensation, however, is reasonably good and is based on the daily catch of about 350 bushels of clams.

Good surf clam harvesting depends on the abundance of clams and gear efficiency. Recent surveys by the Bureau of Commercial Fisheries, an agency of the United States Department of the Interior, have shown new and considerable concentrations of clams within the 100-foot depth contour. Also, the clam industry has developed and is improving a hydraulic clam dredge.

The gear for taking clams is symbolic of this jet age. Surf clams burrow just below the surface of the bottom; they are loosened from the bottom by water jets from a manifold on the dredge. A blade under the dredge raises the clams, guiding them into the catching cage as the dredge moves slowly forward. Powerful pumps on deck furnish water pressure through a large flexible hose. Winches, pulleys, and other hauling devices are maneuvered to bring the catch aboard and dump it on deck. Men pick out the clams from the debris, put them in burlap bags or wire baskets, and stack them on deck. At the end of the day, the catch is unloaded and stored overnight in cold rooms to await processing the next day.

New Jersey processes most of the surf clams landed at her ports. At least eight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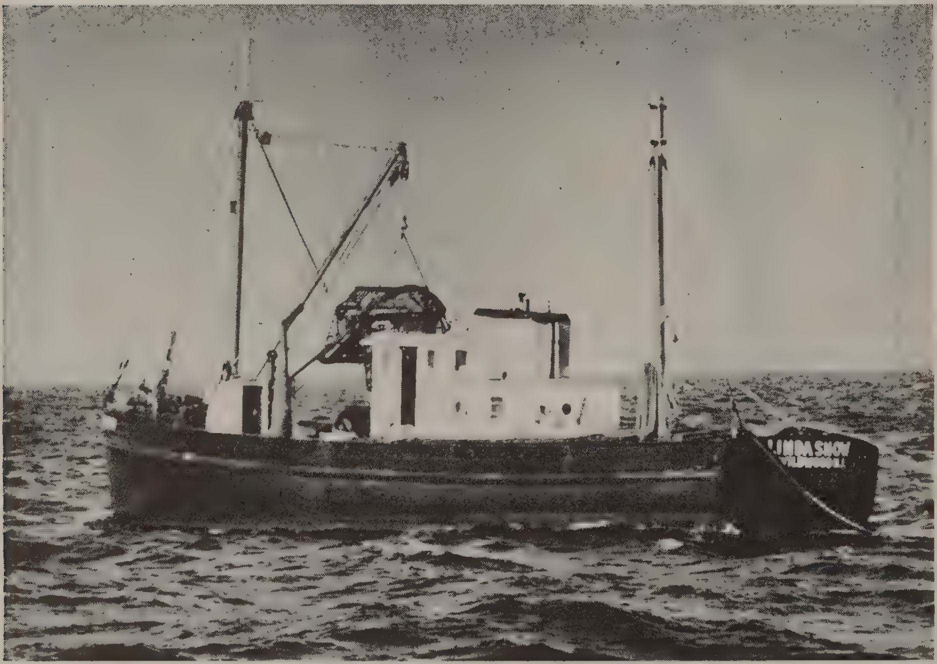
Location of surf clam commercial fishing areas off the New Jersey coast.

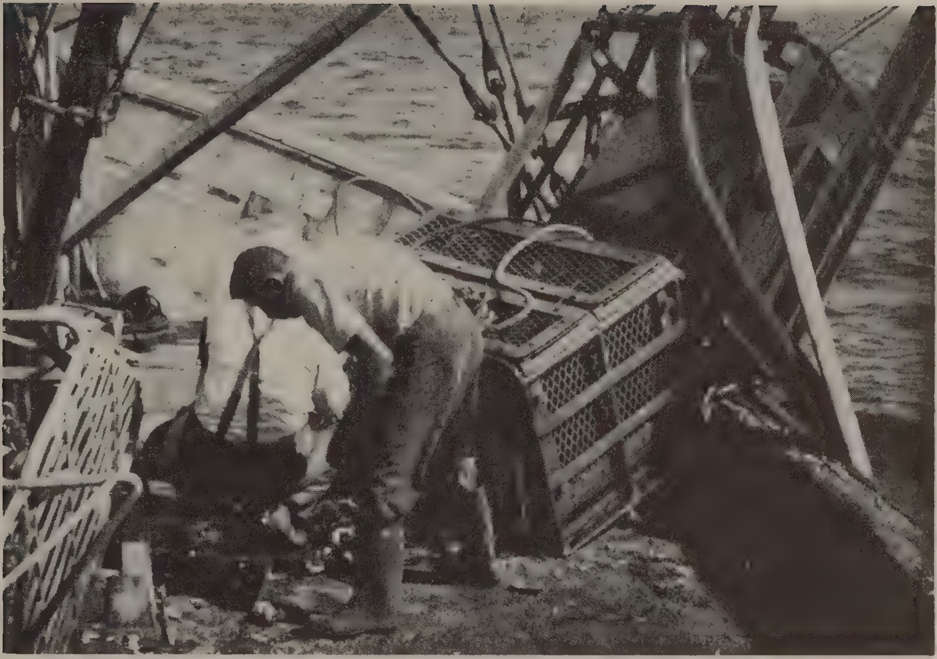
surf clam packers in middle and south Jersey prepare the meats for consumer use. Clams are hand-shucked after a 30-40 second dip in hot fresh water to relax them. Then the digestive gland and outer membrane are separated from the shucked meats and the remainder is washed in fresh water. The meats are chopped, minced or sliced, and the product is canned, made into chowder and canned, frozen, or otherwise prepared for sale. Clam juices are sometimes collected in the clean rinse water, concentrated, clarified, salted, and canned or bottled as clam nectar — a highly nutritional by-product. Surf clam products reach consumers in all parts of the country, ready for preparation as a delectable seafood on the dining tables of the nation.

This industry is young and fast-growing; production has increased rapidly over the past 25 years. Production has depended on a hunt-and-find system in the Atlantic coastal region from the Virginia Capes north to the Canadian border. The surf clam fleet has a history of fishing in areas of greatest clam density close to home ports. Future success of the commercial fishery requires precise knowledge of the natural history and population dynamics that control abundance and distribution of surf clams. Here is where the oceanographer, the marine biologist, and management agencies search for basic facts and pool their findings to advise the industry.

The efficiency of the hydraulic dredge is being constantly improved. One company is experimenting with a water-air lift device to lift clams on deck, thus



A New Jersey surf clam dredger working the clam beds. Part of the day's catch is stored forward in bags. The dredge is suspended over the deck for unloading the catch.



Preparing the surf clam dredge for making a drag. Note the hose that carries water under pressure to the hydraulic jets used to loosen clams from the bottom.

eliminating frequent dredge recovery to empty the catch. The Bureau of Commercial Fisheries is testing a submersible pump attached to the dredge, that would replace the cumbersome flexible hose. This innovation would extend the depth to which dredges could work and would also extend the range of operations. At the present stage of research, however, the submersible pump dredge is about equal in efficiency to the standard hydraulic dredge — experimental changes in dredge design are still in the testing stages. New Jersey's surf clam production will continue to be maintained for a time by the conventional hydraulic dredge. The commercial gear is selective for larger clams, and does not give a true estimate of the total clam population. The Bureau of Commercial Fisheries has devised a special dredge, with fine wire mesh lining, to collect clams of all sizes. This gear gives an accurate picture of the distribution and abundance of clams of all sizes. Other studies are in progress to determine growth rates, natural recruitment, losses to predation and fishing, environment effects, survival, and distribution.

For maximum production, surf clam stocks should be under continuous management. The facts of surf clam life and the vicissitudes of the habitat are being sorted out to achieve the best use of this natural resource so important to the seafood economy of New Jersey and the nation.

Our accumulated knowledge of surf clams has been a team effort. The Bureau of Commercial Fisheries technical forces[1] in biological research, oceanographic exploration, and gear improvement, together with industry are seeking answers to the problems that exist. Conservation agencies in states adjacent to clam-producing waters have contributed parts of the information now available for a better understanding of the factors that will influence the success of this growing seafood industry.

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[1] Bureau of Commercial Fisheries Biological Laboratories, Oxford, Maryland, Boothbay Harbor, Maine, and Woods Hole, Massachusetts, and the Bureau of Commercial Fisheries Exploratory Fishing and Gear Research Base, Gloucester, Massachusetts.

Reprinted from the NEW JERSEY NATURE NEWS, the New Jersey
Audubon Society, Volume XXII, Number 4, December 1967, pages 148-153.

A Proposed Life Cycle of *Minchinia nelsoni* (Haplosporida, Haplosporidiidae) in the American Oyster *Crassostrea virginica*

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J. Protozool. 14(4), 616-625 (1967).

A Proposed Life Cycle of *Minchinia nelsoni* (Haplosporida, Haplosporidiidae) in the American Oyster *Crassostrea virginica*

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SYNOPSIS. A developmental sequence is proposed for the haplosporidan *Minchinia nelsoni* Haskin, Stauber and Mackin, 1966, based on study of oyster infections over the past 5 years in Chesapeake Bay. Uninucleate stages develop by nuclear division into multinucleate plasmodia which proliferate in the tissues by plasmotomy. Relatively small plasmodia containing what are considered to be gametic nuclei originate by unequal plasmotomy of large plasmodia. These have been interpreted to aggregate and fuse to form large plasmodia which contain prozygotes. Pairing and fusion of nuclei occur within each plasmodium to produce zygote nuclei (synkaryons) which undergo division, possibly meiotic, to form sporonts. Sporoblasts differentiate into spores with the development of spore walls and opercula. Cystoid plasmodia develop during times of unfavorable conditions. An anomalous but common sequence involving sexuality and mitosis is described, and the occurrence of various life cycle stages within the host thruout the year is discussed.

SERIOUS oyster mortalities in Delaware Bay which in 1957 almost destroyed the industry in that area, and later in the lower Chesapeake Bay(2,13) led to the discovery by Dr. L. A. Stauber of a parasite designated "MSX" in the tissues of oysters (13,14,15,20). The organism was thought to be a haplosporidan probably in the genus *Haplosporidium*(14,15,20) but until recently a definitive spore stage had not been described.

The parasite was named *Minchinia nelsoni* by Haskin, Stauber, and Mackin(16). Its sporulating stages, discovered in oysters from Chesapeake Bay where the epizootic had substantially spread(2,9) were described by Couch, Farley, and Rosenfield(6). The life cycle has not been proposed previously because the definitive spore stages of *Minchinia nelsoni* had not been recognized until recently.

Stages of *M. nelsoni*, interpreted as stages of plasmotomy, are readily apparent in infected oysters, and several have been discussed by others working with the parasite (see acknowledgments). Haskin et al.(16) described plasmodial stages of the parasite, but no attempt to relate life cycle stages was published until the work of Couch et al.(6).

This report presents a proposed life cycle of *M. nelsoni*, occurring within the oyster, and compares these observations with those made by investigators of other species of *Minchinia*. Since observations on which this paper is based are mostly from static histologic material, interpretations are tentative until more definitive evidence is found.

The family Haplosporidiidae has been a rather neglected group of obscure protistan parasites of invertebrates, but current research on oyster diseases has led to: (a) the discovery of a haplosporidan parasite, *Minchinia costalis*(1, 27), in oysters from the lower Virginia seaside; (b) a revision of the genus *Haplosporidium* which reinstated the genus *Minchinia* which had been erroneously suppressed, listing the species occurring in both genera(23); (c) the description of *Minchinia nelsoni*(16) and its sporulation(6); and (d) the development of a fluorescent antibody technic for diagnosis of plasmodia and spores of *M. nelsoni*(5).

Several investigators have reported life cycle stages of *Minchinia* species in various hosts. Brief summaries of some of the life histories previously proposed indicate problems which have been encountered.

Granata described *M. limnodrili*(12,23) from a freshwater annelid *Limnodrilus udekemianus*. Uninucleate cytozoic stages underwent repeated nuclear division and grew into multinucleate plasmodia which underwent schizogony to repeat the cycle or produce uninucleate gametes. The cytoplasm of the gametes fused and nuclear fusion (karyogamy) produced a synkaryon. Thus arose the sporoblast (zygote) which differentiated into the spore. This paper was the first to show the karyokinetic sequence in detailed figures.

Pixell-Goodrich(21) in her study of *Minchinia chitonis* (Lankester) found heavy infections in 85 of 135 chitons collected within a 5-month period. In sectioned material, only 2 infections were seen in the process of vegetative multiplication by plasmotomy. The rest of the infections had only sporogonic development as follows: Plasmodia rounded up and became encapsulated within host cells which appeared flattened around them. The cytoplasm of the plasmodia then fragmented into a number of different-sized masses containing a variable number of nuclei, but ultimately complete separation into uninucleate gametes occurred. The cytoplasm of paired gametes fused to form binucleate prozygotes (zygotes in which karyogamy has not yet occurred) after which supplementary nuclear fusion formed uninucleate zygotes. Each zygote divided twice producing 4 uninucleate sporoblasts which differentiated into mature spores.

Debaisieux(8) did not report evidence for gamete production or union in *M. chitonis* or *M. nemertis*(23); he suspected, however, that karyogamy (autogamous) took place in the developing plasmodium. He did not separate the schizogonic from the sporogonic phase.

Jírovec(18) described *M. cernosvitovi*(23) from 4 oligochaete worms *Opistocysta flagellum*. Only one worm was heavily infected. Multinucleate plasmodia developed from binucleate stages by mitosis. Recycling of the parasite in the host was by plasmotomy or schizogony. Encystment of large plasmodia within host leucocytes was observed. Large encysted plasmodia fragmented into binucleate and uninucleate stages and eventually, by unknown means, 8 spores were produced in a cyst. A plasmodium was illustrated(18: Fig. 13) which appeared to be fragmenting and contained several large nuclei with duplicate masses of chromatin and smaller nuclei, each with a single chromatin mass within. Jírovec indicated that this process might represent karyogamy, but due to the rarity of the stage, made no definitive interpretation.

Barrow described *Minchinia pickfordae*(3,23) from 9 infections of freshwater snails of 3 genera. Small, uninucleate, cytozoic trophozoites increased in size and, thru karyokinesis, produced large multinucleate plasmodia. "Schizogony" of the mature plasmodium produced, in young infections, merozoites (?) with 1-4 nuclei which recycled in the host; in older infections, fragmentation of plasmodia produced uninucleate sporoblasts which formed binucleate spores by nuclear division. The 2nd nucleus was thought to degenerate in the maturing spore. No evidence was seen for union of nuclei.

Sprague(24) described *M. louisiana* from one specimen of mud crab *Panopeus herbstii*. The animal was heavily infected with sporulating stages. A life-cycle was not proposed from this single infection but many aspects and problems confronting investigators of this group were discussed. Spores(24: Figs. 19-25), a plasmodium with paired nuclei, and stages suggestive of diploid(24: Fig. 11) and haploid (24: Figs. 7-13) mitotic sequences were figured and briefly discussed.

In summary, Jírovec and Sprague saw stages which might indicate sexuality. Some earlier workers (Granata, Pixell-Goodrich, and Debaisieux) seemed convinced that it occurred, whereas Barrow found no evidence for sexuality. Most authors observed plasmotomy but few gave evidence for schizogony. Few reports illustrated complete life-cycles. Evidence for experimental transmission of *Minchinia* species has only recently been reported by Barrow(4) with *M. pickfordae*; however, detailed histologic studies were not given. Pixell-Goodrich's early attempts at transmission were unsuccessful.

MATERIALS AND METHODS

Oysters infected with *M. nelsoni* were studied from samples collected at regular weekly, biweekly, or monthly intervals. Collections were taken from Marumsco Bar, Pocomoke Sound, Md., over the past 5 years, and from isolated samples from Tangier Sound and the Manokin River, Md.(6). The number of oysters per sample varied from 20 (early collection from Marumsco) to 200 (Manokin, 1965) but the most intensively studied material came from 50 oyster samples collected from Marumsco Bar in 1963-65 and from the Manokin River. Over 1,000 infections have been diagnosed and studied. All of the study material came from areas where *M. nelsoni* is the only known species of the genus infecting oysters.

Spores have been found in 11 of 200 Manokin River oysters, 1 of 50 Tangier Sound oysters, and 4 of 88 Chincoteague Bay oysters(7). All of these samples were collected in late June and early July 1965.

The criteria for identification were those recently described by Haskin et al.(15) for the plasmodial stage of the parasite and by Couch et al.(6) for the sporulation stages. Observations were made from living material in fresh squashes, fresh material stained with Quenzel's stain(26) or 0.5% aqueous toluidine blue, and 6 μ transverse histologic sections thru the visceral region of oysters. Tissues were fixed in Davidson's fluid(22) and sections were stained with Harris' hematoxylin and Ziehl's fuchsin-eosin(10) or iron hematoxylin. Photomicrographs were taken at 1,000 ×.

PHASES OF THE LIFE CYCLE

Initial Infection and Asexual Proliferation. The earliest recognizable stages were restricted to the gill epithelium (11). Small plasmodia with few (1-16) nuclei occurred in very light, localized concentrations in gill or palp epithelia (Fig. 1, A-H). Plasmodial nuclei were ordinarily 1-4 μ in diameter, depending on whether nuclear division was occurring. Uninucleate stages (Figs. 1A-D, 2, 3, 4) were rare. The earliest recognized stage of this organism was about 3-5 μ in diameter and had very densely staining, hyaline cytoplasm and a small (1-1.5 μ) nucleus (Fig. 1A). The interphase nucleus contained a basophilic endosome against the nuclear membrane. Mitosis was first indicated by an apparent succession of stages starting with the formation of a dark-staining bar of "Kernstab"(18) across the center of the nucleus (early prophase, Figs. 1A, 2). Successively, endosomes were located toward the center of the bar (late prophase, Fig. 1B, 3); nuclei were elongated along the axis of the bar, and later pointed at both ends, with spindle-fibers

FIG. 1

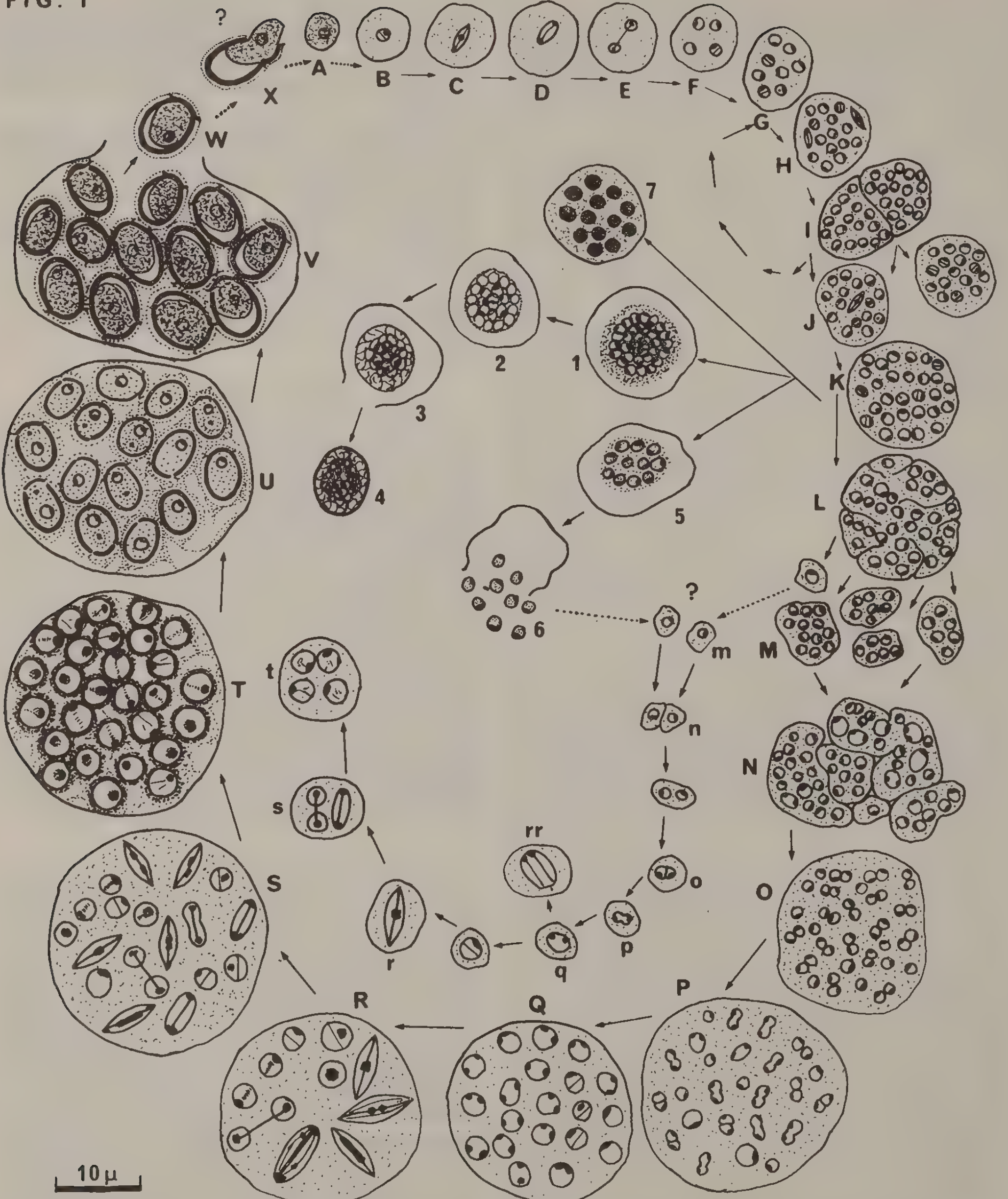


Fig. 1. Idealized scale drawing of the proposed life cycle of *Minchinia nelsoni* in the oyster based on composite stages representative of the sequence. Dotted lines indicate nuclear or unobserved sequences. (A-H) Early karyokinetic development of multinucleate plasmodium from uninucleate amoebula. (I) Plasmotomy producing (J) daughter plasmodia. (K) Enlarged plasmodium. (L) Unequal plasmotomy forming (M) gametic (?) plasmodia. (N) Aggregation and fusion of "gametic" plasmodia. (O) Prozygote stage with paired nu-

apparent (metaphase, Fig. 1C); a basophilic mass was observed at each pole (anaphase) (Figs. 1D, 4). Daughter nuclei occasionally showed the connections of the spindle (Fig. 1E). Spindle remnants were also found in slightly later daughter nuclei. Plasmodia containing 16 or more nuclei presumably developed in this manner (Fig. 1H). Enlarged plasmodia were then observed in the base of the epithelium near the basement membrane. At this stage plasmodia were lined up along the basement membrane, and stages in the process of plasmotomy (Figs. 1I, 1J, 5, 6) first reported by others at shellfish mortality conferences of the past(25) were apparent. Plasmodia apparently pulling apart (Fig. 5) were observed occasionally; however, indications of plasmotomy most often were incomplete or complete fissures thru the center of plasmodia (Fig. 5), probably due to restriction by surrounding tissue.

Proliferation of the parasites resulted in invasion of the adjacent connective tissue and blood sinuses of the gill. Cellular response, characterized by infiltration of small (8 μ) lymphocytoid blood cells, became very evident as the infection spread into connective tissue. Advanced infections (11) were characterized by massive invasion of all tissues. Proliferation of the parasite was by nuclear division, growth, and plasmotomy (Fig. 1G-J).

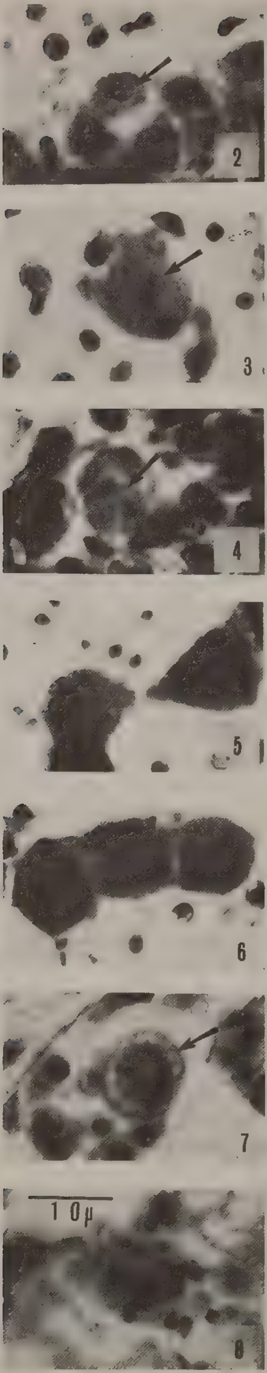
Evidence for true schizogony (asexual production of uninucleate merozoites which recycle in the host) was almost totally lacking for this parasite. The nuclei appeared to gather in the center of a plasmodium (Figs. 1, 5, 7) with concomitant degeneration of the cytoplasm, rupture of the plasmodial membrane and release of the nuclei into the tissue (Figs. 1, 6, 8). These stages were considered to be moribund because of their basophilic appearance and because the nuclei did not appear to be enclosed in cytoplasm. Live vegetative organisms (Fig. 40) were usually oval and had irregular outlines because of pseudopodial projections which often extended a short distance from the plasmodium. Very slow movement of pseudopodia has been observed in living material, and plasmodia may have moved thru tissues in this manner.

Sexual Phase. In our material it is interpreted that plasmodia grew into large (20 μ) amoeboid forms (Fig. 1K) with 30 or more nuclei, followed by unequal plasmotomy (Figs. 1L, 9) to produce 5 or 6 small plasmodia with 1-5 nuclei (Figs. 1, 10). These smaller, usually multinucleate plasmodia, which are believed to be gametic plasmodia, appeared to have aggregated (Figs. 1N, 11) and fused, resulting in a large (20-25 μ) multinucleate prozygote stage (Fig. 12) comparable to the prozygote stage described by Pixell-Goodrich(21) but originating presumably from fusion of multinucleate plasmodia. Aggregated multinucleate plasmodia of varying size, some containing large nuclei and others small nuclei, were observed, perhaps indicating partial fusion of nuclei. The prozygote nuclei within the plasmodium presumably paired and fused (Figs. 1O, 14). Criteria for distinguishing nuclear fusion were: (a) paired nuclei (1-2 μ) in interphase (Fig. 1O); (b) fusing nuclei that shared a common membrane but still possessed their original shape (Fig. 1P); and (c) relative size of presumed zygotic nuclei within plasmodia (3 μ) opposed to the vegetative nuclei of the proliferative stages and spores (1.5 μ). Two endosomes were present at first in the zygotic nucleus, but apparent fusion resulted in a large (3-4 μ) interphase nucleus containing one large peripheral endosome (Fig. 1Q). The synkaryon stages either migrated to or developed only in or near the digestive diverticula. Nuclear divisions, presumed to be a meiotic sequence, occurred (Figs. 1R-S, 15, 16) to produce sporoblasts (Figs. 1T, 17, 18). This sequence appeared to be closely related to successful sporulation, which was detected only in sporulating oysters.

A similar sequence of nuclear events (Figs. 1m-t, 22-35), which occurred commonly but which was thought to be an abortive sporogonic phase of the parasite, was recognized in the fall and winter. Vegetative uninucleate stages, considered to be gametic (Figs. 1L-M, 22), probably arising from unequal plasmotomy (Fig. 1M), but possibly from the free nuclei mentioned previously (Figs. 1, 6) presumably paired (Fig. 1n) and fused to form a binucleate prozygote stage (Figs. 1n-o, 23). Paired and fused nuclei of resulting binucleate stages (Figs. 1o, 1p, 24, 25) were observed; presumably they formed a synkaryon (Figs. 1q, 26, 27). Two divisions (meiotic?) (Figs. 1q-t) appeared to occur in this sequence because an abundance of uninucleate (Fig. 1r), binucleate (Fig. 1s), and quadrinucleate (Fig. 1t) forms were usually present, and the karyokinesis produced very large (5-9 μ) mitotic figures (Figs. 1r-s, 28-34). The presence of paired and partially fused nuclei (Figs. 1O, 1P, 1o, 1p, 24, 25); the presence of large (3 μ) nuclei with 2 randomly placed endosomes (Figs. 1Q-q, 22-27); the extreme difference in nuclear mass before and after fusion (Figs. 22-28); and the occurrence of an atypical anaphase figure (Figs. 1rr, 35) which had 2 basophilic masses at one pole of the nucleus and 2 distinct spindles, were indications that nuclear fusion occurs. This last figure was thought to be the product of incomplete fusion of the endosomes within the synkaryon. Degeneration was apparent in many of the stages in the sequence, and normal-appearing stages that had 4 or more enlarged nuclei were uncommon. This atypical sequence usually occurred in the connective tissue (as opposed to the digestive diverticula which were sites of successful sporogony) and was not seen to culminate in sporulation.

Sporogony. Sporulation occurred only in the digestive diverticula after the division of synkarya (Fig. 1N-S). The nuclei produced by mitosis remained large (3-4 μ) and rem-

clei. (P) Prozygote stage with fusing nuclei. (Q) Synkaryon stage with enlarged diploid (?) nuclei. (R) First meiotic (?) division, karyokinetic sequence clockwise. (S) Second meiotic (?) division. (T) Early sporont. (U) Immature sporocyst (containing "haploid" spores). (V) Mature sporocyst and spores. (W) Free spore. (X) Idealized escape of sporoplasm. (1-4) Encystment sequence. (1) Cytoplasmic contraction. (2) Formation of dense outer coat. (3) Rupture of plasmodial membrane. (4) Mature cyst. (5, 6) Release of nuclei. (7) Moribund plasmodium. (m-t) Atypical sexual sequence and meiosis (?) (m) "Gametes". (n) Fusion of "gametes". (o) Prozygote with paired nuclei. (p) Nuclear fusion. (q) Synkaryon with 2 endosomes. (rr) Anaphase figure exhibiting double endosomes and spindles. (r) Metaphase of 1st division. (s) 2nd division (may be reduction. (t) Quadrinucleate, post-division plasmodium. This form when found usually appears to be degenerating.



Figs. 2-8. 2. Vegetative uninucleate-stage, nucleus in early prophase. 3. Vegetative nucleus in late prophase or early metaphase. 4. Vegetative nucleus in anaphase. 5. Trophozoites undergoing plasmotomy. 6. Plasmotomy producing daughter plasmodia. 7-8. Development and release of free nuclei.

nants of spindles were present (Fig. 1T). Altho the mechanism is not understood, small (1-1.5 μ) nuclei appeared within developing sporoblasts (Figs. 1T, 17). At this time the cytoplasm of the sporocyst fragmented and began to condense around the membrane of the nucleus to form the spore wall and capsule (Figs. 1T-U, 18). The immature spores (Figs. 1U, 19, 41, 42) developed in the manner described by Couch et al.(6). The orifice appeared first, followed by the operculum and spherule (Fig. 1U). Mature spores (Figs. 1V, 20, 43) had thickened spore walls and lacked spherules. The acid-fast reaction is probably the most definitive method of determining spore maturity, since in the immature stages, the sporoplasm developed acid-fastness, staining first pink and at maturity bright red(6, 10). Basophilia, as indicated by staining with Harris' hematoxylin, toluidine blue, and Quensel's stains, decreased as the spore matured.

Mature sporocysts probably rupture to release mature spores (Figs. 20, 21, 43) into the lumens of the diverticula (Fig. 1W). In the oyster, *M. nelsoni* spores may escape into the outer environment by passing thru the alimentary canal and out with the feces. Emergence of amoebulae from *Minchinia* spores under natural conditions has not been seen, nor have spores been found in association with initial infections. Sporulation of *M. nelsoni* differed from that in *M. costalis* in a number of significant ways:

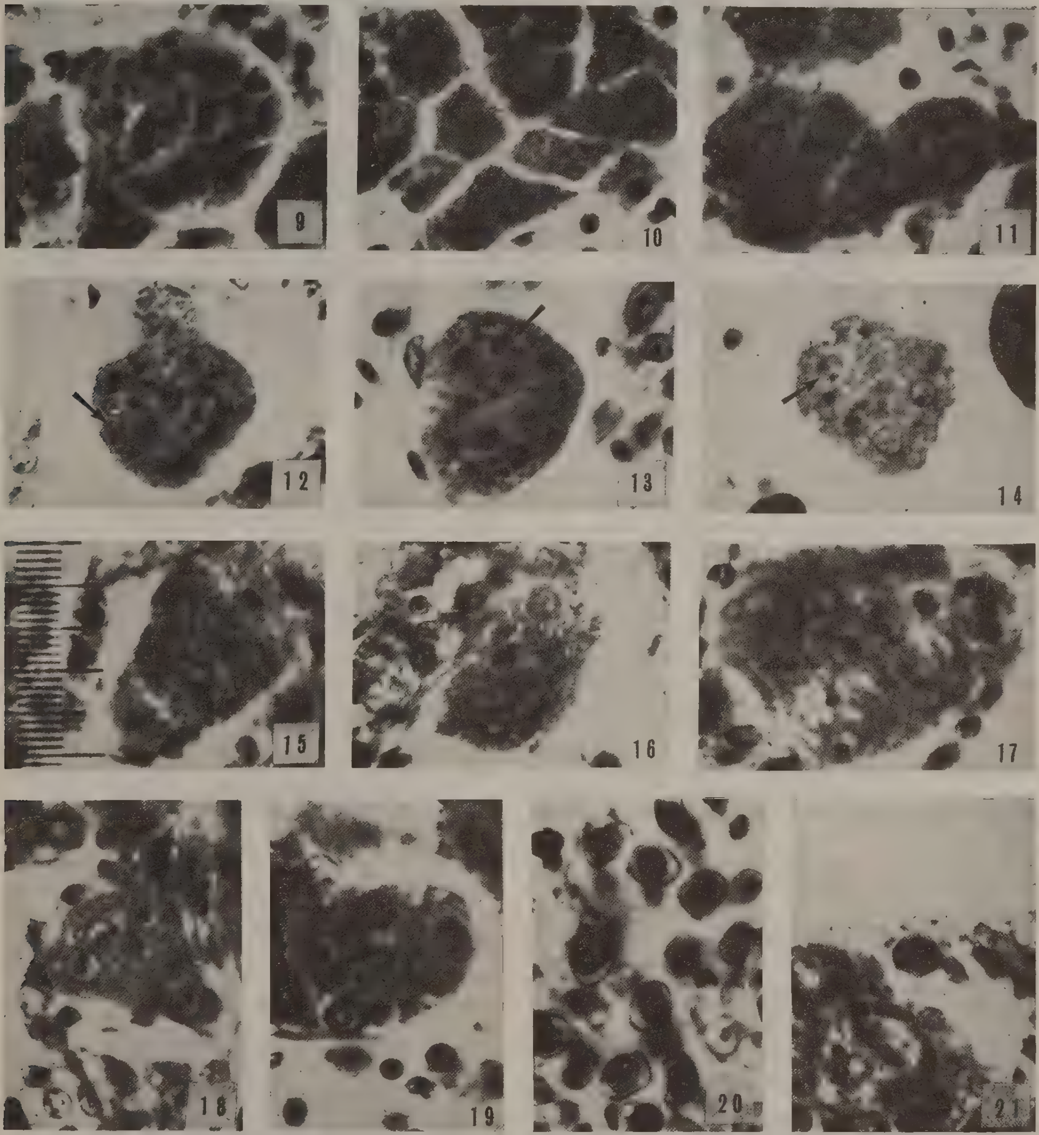
(a) Sporulation in *M. nelsoni* was rare; *M. costalis* sporulated regularly during the early summer(1,7,27).

(b) *M. nelsoni* appeared to sporulate only in live oysters (6). Mature spores of *M. costalis* occurred only in dead or dying oysters(1,6,7).

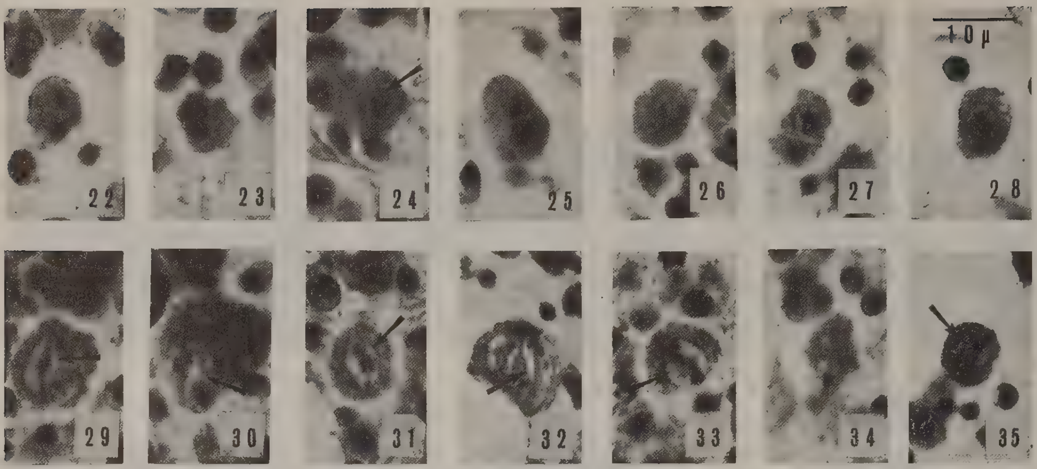
(c) Sporulation of *M. nelsoni* usually occurred in the digestive diverticula of oysters, whereas *M. costalis* sporulated in all tissues.

Cystoid Stages. Under adverse environmental conditions —possibly due to changes in salinity, temperature, host physiology, immune reactions, or other factors—vegetative forms of the parasite appeared to undergo a sequence of changes suggestive of encystment. Plasmodia appeared plasmolized; the nuclei became tightly packed; and a clear area was observed between the cytoplasmic mass and the plasmodial membrane (Figs. 1-1, 36). A faint membrane was at first observed around the cytoplasmic mass, and the endosomes of the outer nuclei disappeared (Figs. 1, 2, 37). The organism obviously decreased in size, was more compact, denser, and basophilic (Figs. 1, 3, 38). The resulting stage was an oval, densely staining cyst-like stage with usually 1-4 nuclei packed tightly in the center of the surrounding vacuolated cytoplasm (Figs. 1, 4, 39). Occasionally faint to moderate acid-fastness appeared; however, this feature never approached the intensity of that seen in mature sporoplasms. The original plasmodial membrane often appeared ruptured and free "cysts" could be found in a variety of locations thruout the host, frequently as phagocytic inclusions. The cystoid sequence was most common in recovering oysters(11). Excystment has never been seen.

One other stage observed was a round, often phagocytized, eosinophilic, multinucleate plasmodium containing small, very basophilic nuclei (Figs. 1, 7). I believe, as do others who have described similar forms from other species of *Minchinia*(3,18,24), that this stage is moribund and has little or no significance in the life history.



Figs. 9-21. 9. Unequal plasmotomy of large plasmodium. 10. Daughter plasmodia (gametic plasmodia ?) originating by equal plasmotomy. 11. Aggregation and fusion of gametic (?) plasmodia. 12. Prozygote with paired nuclei. 13. Prozygote stage with fusing nuclei. 14. Synkaryon stage. 15-16. Division of synkaryon. 17. Cytoplasmic condensation around post-division nuclei. 18. Newly formed spore walls around post-meiotic nuclei. 19. Immature spores. 20. Mature spores in sporocyst. 21. Mature spore, showing operculum. (1 micrometer unit equals 1 μ.)



Figs. 22-35. Atypical sexual phase. 22. Uninucleate "gamete." 23. Binucleate prozygote. 24. Karyogamy of prozygotes. 25. Quadrinucleate prozygote stage showing fusion of nuclei. 26. Uninucleate synkaryon stage showing 2 endosomes. 27. Uninucleate synkaryon stage showing fusion of endosomes. 28. Uninucleate synkaryon stage, early prophase. 29. "Diploid" metaphase. 30-31. Synkaryon early anaphase. 32-33. Synkaryon late anaphase. 34. Synkaryon telophase. 35. Abnormal synkaryon in anaphase showing double endosomes and spindles.

Seasonal Aspects of Life History Stages. Initial infections have been found in samples collected during every month of the year(11) but they occurred most regularly when oysters were feeding heavily (April thru September). A water-borne infective particle is indicated. Proliferation (plasmotomy, nuclear division) occurred in all active infections thruout the year, but was less apparent during the cold months (December through March) and during periods of lower salinity, at which times the cystoid sequence was most common. Cystoid stages also occurred at other times, when the host environment appeared to be unfavorable for the parasite. Sporogonic stages were found for the first time in July 1965(7) after 5 years of sampling, altho isolated examples of what are considered prespore stages had been seen in many samples. "Abortive sporogonic stages" were common in fall and early winter, but also appeared occasionally at other times.

DISCUSSION

The sequence of life cycle stages proposed here for *M. nelsoni* agrees most closely with that of Pixell-Goodrich (21) for *M. chitonis.* The basic difference is that *M. chitonis* goes thru the sexual phase and sporulation within a cyst composed of host leucocytes. This process necessitates an autogamous fusion of gametes arising from a common plasmodium. Uninucleate gametes produce uninucleate zygotes which form 4 spores per zygote by a sequence of 2 divisions, conceivably meiotic. The original host-cell cyst with many zygotes would therefore contain many spores. Possibly, as Pixell-Goodrich stated, exchange of chromatin material might have occurred earlier in the cycle by plastogamy of haploid plasmodia before encystment.

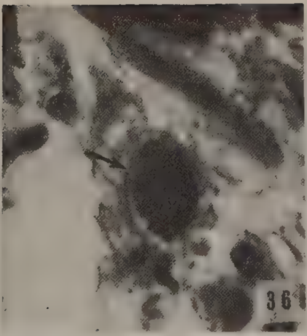
With some rearrangement of stages, Jírovec's *M. cernosvitovi* might also fit the life cycle described for *M. chitonis.* This organism also goes thru a fragmentation of large plasmodia into uninucleate and binucleate forms while it is enclosed within a cyst composed of host cells. Mitotic division associated with sporulation is a well established observation in the genus *Minchinia*(3,6,8,12,18,21,24) and the occurrence of definitive spore numbers within sporocysts in 2 species(18,21) strongly suggests to me the presence of a sexual sequence.

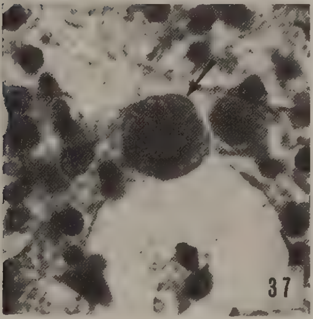
Some of the stages figured by Sprague(24) for *M. louisiana* appear similar to the gametogenic and sporogonic sequence proposed for *M. nelsoni*; namely, the paired nuclei in his Figures 1-5 occurring within a multinucleate plasmodium, and a mitotic sequence(24, Figs. 1-14) apparently leading to sporocysts containing many spores.

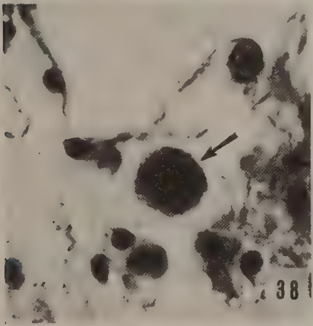
In his study of *M. nemertis* and *M. chitonis,* Debaisieux (8) also saw stages similar to those above. He observed paired nuclei and large nuclei with paired endosomes that suggested the occurrence of karyogamy. He figured different plasmodia with nuclei of 2 distinct sizes in respective plasmodia, with accompanying karyokinetic figures of 2 distinct sizes in both species. Possible haploid and diploid phases are suggested. Sporocysts with many spores were produced. The stages seen by Debaisieux seem comparable in many respects to those in *M. nelsoni.*

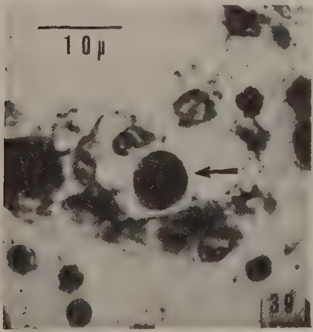
Granata(12), as was stated earlier, illustrated karyokinetic sequences of both large and small nuclei in *M. limnodrili* and described gametogenesis and karyogamy. Altho his sequence as a whole was a little different from those already mentioned for *M. nelsoni,* the stages and general life history appeared to be closely similar.

The process of spore formation offers an interpretive problem which will probably require intensive cytochemical









Figs. 36-39. Encystment sequence. 36. Cytoplasmic contraction. 37. Basophilic and degenerating peripheral nuclei. 38. Vacuolation of peripheral edge of plasmodium. 39. Elongated cystoid stage with central nuclei.

and electron microscope studies to resolve. Jírovec(18) and Couch et al.(6) were non-committal about the origin of the spore wall, but indicated that the nucleus is considerably larger in young spores and sporoblasts. Barrow(3), Sprague (24) and Couch et al.(6) stated that the size of the nucleus decreased as the spore matured, and 2 authors(3,24) indicated a cytoplasmic origin for the spore wall. The walls of *Minchinia* spores have been found by most authors to be extremely basophilic with iron hematoxylin, but DNA-specific stains used in the past(21) have not supported the theory of nuclear origin.

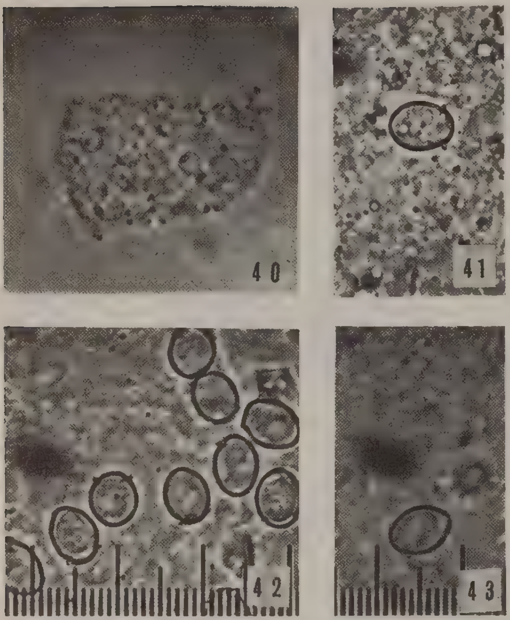
The transmission of haplosporidan parasites has puzzled most investigators. Pixell-Goodrich(21) conducted extensive experiments over several months with 7 species of associated organisms as possible vectors. Spores of *Minchinia* which passed thru the alimentary canal of some of these organisms were unchanged, and no subsequent infections were diagnosed either in chitons or any of their associates. Barrow(5) only recently reported indirect evidence for possible transmission of *Minchinia pickfordae*.

Because the spores of *M. nelsoni* were only recently identified, no information is available concerning their infectivity. Possibly spores may have to go thru a maturation process or be subjected to conditions such as freezing, drying, or enzymatic digestion to become infective.

The significance or fate of the cystoid stage is unknown, but several possibilities exist. It may be a degenerative moribund form or it may be a resistant stage which survives adverse environmental conditions and eventually reinfects the same host individual. Again, it might be infective to another host.

The facts that: (a) Sporulation in *M. nelsoni* occurred so rarely; (b) the vast majority of infections seen over the past 5 years have had only vegetative stages which often developed atypical sequences and forms (abortive sporogonic sequence and cystoid forms); and (c) the parasite caused heavy mortality in host populations, may indicate that the oyster is a new host for this parasite and not well suited for its normal development. Sprague(25) and others (see acknowledgments) hypothesized, and I fully concur, that the parasite may normally occur within some associated organism living in the vicinity of oyster populations and may sporulate regularly to provide forms infective to both oysters and the other host. The occurrence in initial infections of uninucleate amoeba-like forms that resemble the sporoplasm in size and structure and the apparently extreme localization of infection indicate at this time that the uninucleate stages originate from spores (Fig. 1X, idealized drawing). It appears that few infective bodies are necessary to produce infection. The apparent absence of identifiable spores in initial infections could be accounted for by their small size and scarcity.

Levine(19), and subsequently Honigberg et al.(17), indicated that no sexual cycle exists in the Haplosporida, but information gathered from the present study, and papers by



Figs. 40-43. Photomicrographs of live parasites. 40. Plasmodium with vegetative interphase and early prophase nuclei. 41. Immature spore with nucleus and spherule. 42. Immature spores with heavy walls, and opercula. 43. Mature spore showing shrinkage of sporoplasm, heavy wall, and operculum. (1 micrometer unit equals 1 μ).

others(8,12,18,21,24), suggests that sexuality does exist in this group and is involved in spore formation.

Complete understanding of a life cycle depends on (a) long-term studies of epizootiology, histopathology, and cytology of the parasite and its host; (b) culture and study of the organism thru its life history; and (c) experimental transmission of the parasite from known infected material or cultured material to an uninfected host. This study was concerned with the first aspect mentioned above; therefore only tentative interpretations and conclusions have been drawn. Definitive answers to questions concerning acquisition of infection, schizogony, and sexuality may not be forthcoming until culture and transmission have been achieved, and it has been determined whether or not another host exists.

In 1959 the following institutions embarked on a cooperative program of research on the causes of oyster mortality, especially *Minchinia nelsoni* (MSX): Galveston Marine Laboratory, Agricultural and Mechanical College of Texas, Galveston, Texas; Hiram College, Hiram, Ohio; Natural Resources Institute of the University of Maryland, Solomons, Maryland; New Jersey Oyster Research Laboratory, Bivalve and Cape May Court House, New Jersey; University of Delaware Marine Laboratory, Lewes, Delaware; the U.S.F.W.S. Bureau of Commercial Fisheries Biological Laboratory, Oxford, Md.; and Virginia Institute of Marine Science, Gloucester Point, Virginia. Annual workshop conferences, with participants from the institutions named, were held. Because of the urgent need to rehabilitate the oyster industry there was, thru the year 1965, free exchange of information. Several formal presentations of ideas and data on possible life cycles were made as early as 1961. The best documented instance was during the 1965 annual conference when a panel discussion of the life cycle was held and each participant distributed mimeographed copies of his paper. At this panel discussion the following suggestions were made by participants: (1) that MSX was a haplosporidan and on this basis developed like other haplosporidans, namely, proliferation by plasmotomy to produce plasmodia or by schizogony to produce merozoites, which in turn developed into plasmodia by mitotic division of nuclei and growth; (2) that MSX was a chytriid fungus with a life-cycle vastly different from the cycle which is proposed in this paper; (3) that there was no evidence for cyclic behavior, and life-cycle determination was impossible without laboratory isolation of the parasite; (4) that the parasite was transmitted via a water-born infective particle; (5) that there was a direct relationship between the number of infective particles and the intensity of infection and (6) that another host was involved. Because several people in the different cooperating institutions had vested interests in the life-cycle problem as well as in many other aspects of oyster disease research, and in deference to their interests, I requested a conference of these people in August 1966 to consider the possibility that all might collaborate in publishing a proposed life cycle. Because of lack of unanimity of opinion about parts of the cycle among those who attended (some did not attend), it was agreed that each would publish separately. No presentation during the 1965 panel discussion resembled the life cycle presented by me at the 1966 mortality conferences—which is the basis of the present paper.

Dr. Melbourne R. Carriker aided, advised, and encouraged the establishment of the original disease-monitoring program which ultimately provided most of the study material for this presentation; Dr. Aaron Rosenfield and Dr. Carl Sindermann advised, and encouraged me thruout the study; Mrs. Virginia A. Liddell and Mrs. L. Cecelia Sullivan undertook many and varied activities connected with the processing of tissues and preparation of sectioned material; and the Maryland Department of Chesapeake Bay Affairs made available their boats and personnel for collection of materials.

Appreciation is expressed to Drs. Victor Sprague and John G. Mackin for critical review of the manuscript, without implication of responsibility, however, for my interpretations and conclusions.

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THE ALASKAN STREAM

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Seattle, Washington, June 1965

ABSTRACT

The general oceanographic features and continuity of the Alaskan Stream are discussed using data obtained during May through August 1959. The Alaskan Stream is defined as the extension of the Alaska Current which flows westward along the south side of the Aleutian Islands. It is continuous as far westward as long. 170°E where it divides sending one branch northward into the Bering Sea and one southwestward to rejoin the eastward flowing Subarctic Current.

Observed westward velocities near Atka and Adak Islands were in excess of 100 cm/sec, but maximum geostrophic velocities (referred to 1000-m level) of only 30 cm/sec were obtained from station data. Volume transport, computed from geostrophic currents, was approximately 6×10^6 m^3/sec.

Evidence is presented that the Alaskan Stream is driven primarily by the action of wind stress. The observed narrowness of the stream and continuity of transport also support the view that it is a western boundary current related to the general distribution of wind stress.

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ACKNOWLEDGMENTS

I am indebted to Dr. W. B. McAlister, Bureau of Commercial Fisheries, for interesting discussions concerning wind-driven transport in the North Pacific Ocean, to Dr. Maurice Rattray, Jr., University of Washington, for suggestions and advice during preparation of the paper, and to Mr. Fred C. Cleaver, Bureau of Commercial Fisheries, for the opportunity to accomplish this work.

The assistance of Miss Virginia Coleman and Mrs. Edith Wells is also gratefully acknowledged.

INTRODUCTION

The Alaska Peninsula and Aleutian-Komandorski island chain form a partial land barrier across the northern North Pacific Ocean that has a marked effect on the oceanography of the Subarctic Pacific region. A dominant oceanographic feature is the large westward transport of water along the southern side of the chain. Twenty years ago this westward flow was relatively unknown and not considered of sufficient magnitude to be included as one of the current systems of the Pacific Ocean (Sverdrup *et al.*, 1942). Even today an accurate description of this flow cannot be found in either recent general texts of the ocean, such as King (1963), or in recent comprehensive reviews of the oceanography of this region—Fleming (1955), Muromtsev (1958), Uda (1963), and Dodimead *et al.* (1963).

The purpose of this study is to describe the nature and extent of this westward flowing current, the Alas-

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Received for publication October 1965. Original, English.
Source: Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, Washington, D.C. INPFC Doc. 795.
Bull. 21, Int. North Pac. Fish. Comm., 1967.

kan Stream, and to evaluate its importance as a major current system of the Pacific Ocean.

BACKGROUND

According to Sverdrup *et al.* (1942), water between the Aleutian Islands and lat. 42°N is formed by mixing of the Kuroshio and Oyashio Current systems, and flows eastward as the Aleutian (Subarctic) Current[1]. Near long. 180°, the Subarctic Current divides. One branch flows northward into the Bering Sea. The main current continues eastward to the North American coast where it again divides, sending one branch southward along the west coast of the United States and the other northward into the Gulf of Alaska where it forms a counterclockwise gyre (Fig. 1).

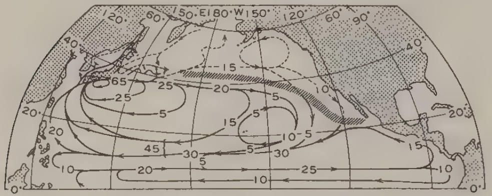

FIGURE 1. Transport chart of the North Pacific. Numbers indicate volumes transported ($m^3/sec \times 10^6$) above 1500 m depth. Dashed lines show cold currents; solid lines show warm currents. (From Sverdrup *et al.*, 1942.)

Recent investigations indicate that the northward branch, which is usually considered as the Alaska Current, divides again near long. 160°W; one part flows southward to rejoin the Subarctic Current and completes the Alaska gyre, while the other continues westward along the Aleutian Islands. The latter current is considered in this paper to be the Alaskan Stream.

The term Alaskan Stream has been used before, but has not been well defined. Using data obtained near Unimak Pass (long. 165°W) from several oceanographic stations in 1935 and surface observations in 1938, Goodman and Thompson (1940) defined the Alaskan Stream as a water mass having relatively permanent boundaries and characterized by dilute water believed to be carried into the area as a stream or eddy from the Gulf of Alaska. They attributed the term Alaskan Stream to Schott (1935), but Schott (plate XXX) gives the name as Alaska *Ström* which also translates as Alaska Current, and apparently refers to the Alaska Current rather than to a separate system.

Since these early investigations, this stream or water mass has been denoted in various ways. Doe (1955) identified water masses in the eastern Pacific Ocean and delineated a Coastal Water Mass southward of the Alaska Peninsula; Fleming (1955) divided the area under consideration into two regions, Alaska Coastal and Western Gyral; Kitano (1958) referred to the current south of the Aleutian Islands as a Returning Flow; and Muromtsev (1958) denoted the current moving northward around the Gulf of Alaska and into the Bering Sea through passes in the eastern Aleutian Islands as the Alaska Current.

Bennett (1959) revived use of the term Alaskan Stream. Using data collected by various agencies during 1955, he defined it as that stream south of the Alaska Peninsula, adjacent to the coast and about 100 miles wide. However, the 1955 data were not adequate to define the extent of the Alaskan Stream west of long. 160°W.

PREVIOUS STUDIES

Although many oceanographic cruises had been conducted prior to 1955 in the general vicinity of the Aleutian Islands, most were exploratory. Many consisted of a single line of stations through the area (e.g., Japan Agricultural Technical Association, 1954). Some results of these early cruises have been summarized by Fleming (1955) and by Dodimead *et al.* (1963).

Northward flow through Tanaga Pass was found by Barnes (1936) and further discussed by Barnes and Thompson (1938). Ratmanoff (1937) noted a northward flow through most Aleutian passes, and indicated that the main flow was northward between Attu Island and the Komandorski Islands.

Mishima and Nishizawa (1955) used the limited data from the 1953 and 1954 cruises of the *Oshoro Maru* (which were supplemented with data from the 1929 cruise of the *Carnegie*, the 1933 cruise of the *Gannet* and the 1935 cruise of the *Itsukushima Maru*) to describe conditions in the Aleutian area. They reported that a warm water mass of low salinity flowed westward south of the Aleutian Islands and extended to long. 165°E and that there was a flow northward into the Bering Sea through several shallow channels between the Aleutian Islands, but that the main current turned north or northeastward into the Bering Sea after passing over the Aleutian ridge near Attu Island. They also noted that a large clockwise eddy of this warm water was formed to the south or southwest of Attu Island. This analysis was a reasonably good description of the western terminus of the Alaskan Stream, but because of the few stations and the long time span more extensive observations were needed to document these conclusions.

Solutions to problems concerning the distribution and migration routes of the Pacific salmon which confronted the International North Pacific Fisheries Commission in 1953 required knowledge of current systems and the distributions of water properties in the northern North Pacific Ocean. Large catches of salmon near the Aleutian Islands focused attention on that area. Kitano (1958) referred to the current south of of the Aleutian Islands as a Returning Flow with a strong northward component at long. 175°W and 180°, and stated that westward of long. 180° the warm water may occur intermittently as a Cut-Off Warm Water Mass. However, Hirano (1961) reported that water having a relatively high temperature and low salinity flows westward along the southern coast of the Aleutian chain, part going northward and entering the Bering Sea, mainly through the area between Attu Island and the Komandorski Islands, and that a major portion of this water proceeds westward until it turns southwestward off the Kamchatka Peninsula.

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[1] The term Subarctic Current is used in this paper.

Uda (1963), using data available for the years 1955 to 1958, defined an Alaska Stream Extension that developed westward of Unimak Island in spring and summer and extended out to the end of the Aleutian chain by August. He also mentions that water in the Extension which moves northward through the Aleutian passes is affected by a South Aleutian Warm Current; the origin and extent of this current is not clear.

During spring and summer 1957, extensive temperature observations were obtained southward of the Aleutian Islands (Favorite and Pedersen, 1959a) which showed continuity of a warm (greater than 4.0°C) water mass from long. 160°W to 175°E (Callaway, 1963). During 1958, observations of temperature, salinity and dissolved oxygen were obtained (Favorite and Pedersen, 1959b) which showed the distribution of these properties from long. 155°W to 175°E (Dodimead and Favorite, 1961), but the station spacing was not adequate to show continuity of water transport. Based upon information obtained from these cruises, plans were made to obtain more extensive and adequate data in 1959.

Sources of Data

Between May and August of 1959, oceanographic observations were obtained aboard two chartered fishing vessels: MV *Pioneer* and MV *Tordenskjold* (Favorite *et al.*, 1961). Oceanographic work was limited to observations that did not interfere with the fishing operations. Samples were taken at standard intervals from the surface to either 300 or 1,000 m at 30-mile intervals southward of the Alaska Peninsula and Aleutian Islands along seven meridians: 160°W, 165°W, 170°W, 175°W, 180°, 175°E, and 171°E (Fig. 2).

Chemical analyses were performed at a temporary laboratory established at the U.S. Naval Air Station, Adak, Alaska, and at the Bureau of Commercial Fisheries Biological Laboratory, Seattle, Washington. Calculation of the anomalies of dynamic height was accomplished by machine computation.

This paper is based primarily upon these data. Additional data from 1959 cruises of the *Hokusei Maru* and *Oshoro Maru* (Faculty of Fisheries, Hokkaido University, 1960) have been utilized to describe conditions west of long. 172°E, and data from the 1959 cruise of the HMCS *Oshawa* (Fisheries Research Board of Canada, 1959) have been used to determine transports south of Kodiak Island, long. 150°W.

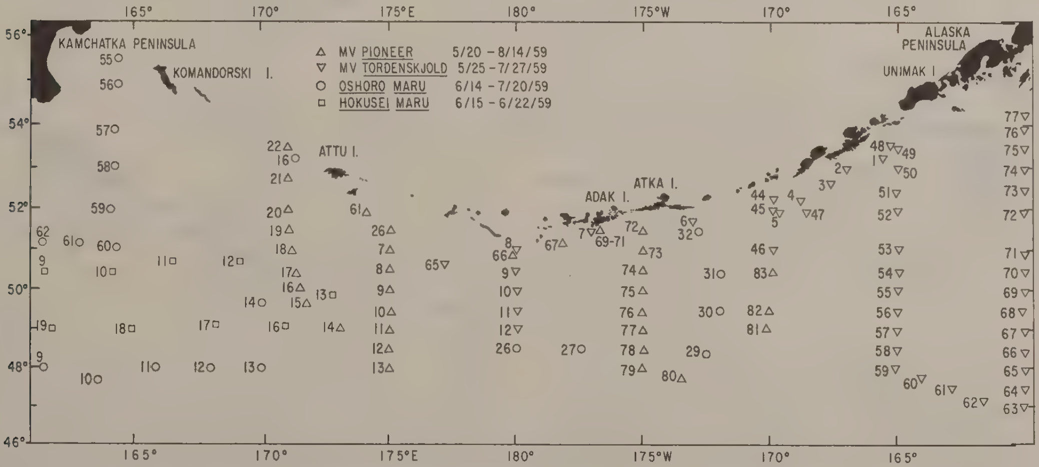

FIGURE 2. Location of oceanographic stations, 1959.

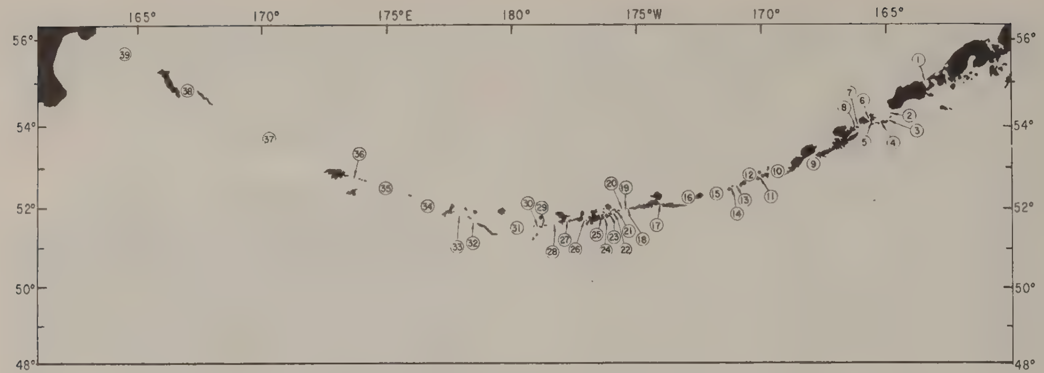
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FIGURE 3. Aleutian-Komandorski island chain showing major passes (see Table 1).

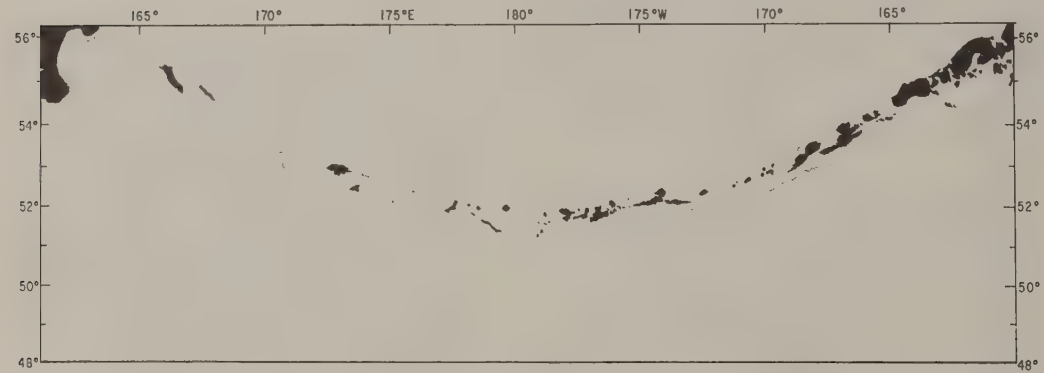
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FIGURE 4. Aleutian-Komandorski island chain showing configuration of 300-m depth contour (see Table 1).

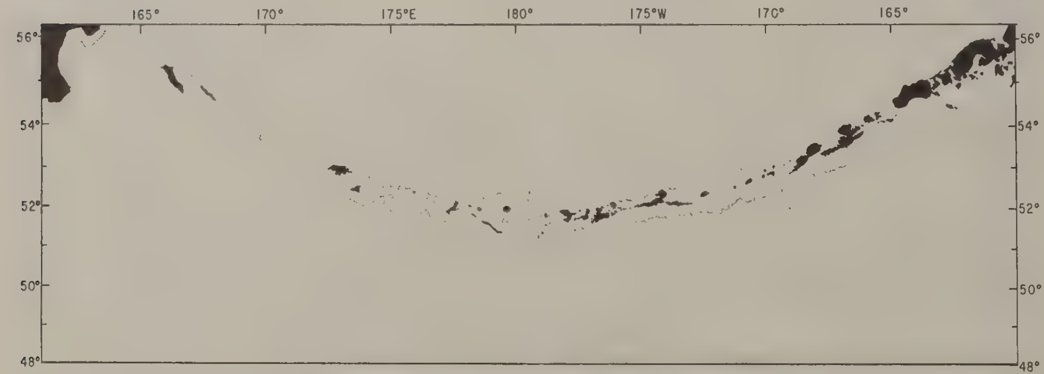
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FIGURE 5. Aleutian-Komandorski island chain showing configuration of 1000-m depth contour (see Table 1).

BATHYMETRY

Island Chain

The Aleutian-Komandorski island chain, which extends from the Alaska Peninsula to the Kamchatka Peninsula, separates the North Pacific Ocean from the Bering Sea. Exchange of water can take place in 39 of the major passes (Fig. 3). Only six passes—Yunaska (13), Amukta (15), Amchitka (31), Buldir (35), Near (37) and Kamchatka (39)—have sill depths exceeding 300 m (Fig. 4), and only Amchitka, Near and Kamchatka passes have sill depths exceeding 1,000 m (Fig. 5). Only the passes between the Alaska Peninsula and Attu Island are considered in this paper. Cross sectional areas and sill depths of these passes are tabulated (Table 1). Areas have been obtained by planimetering vertical sections based on bathymetric data obtained from various U.S. Hydrographic Office charts. The total cross sectional area eastward of Attu Island, 130 km^2, is in good agreement with that obtained by Udintsev *et al.* (1959).

Table 1. Cross-sectional areas and sill depths of major passes or straits through the Aleutian Islands.

Location	Pass or Strait[1]	Area ($m^2 \times 10^6$)	Max. sill depth (m)
163°W–165°W			
Alaska Peninsula to Krenitzin Islands	1 False	0.1	35
	2 Unimak	0.9	60
	3 Ugamak	0.2	45
165°W–170°W			
Tigalda Island to Herbert Island	4 Derbin	0.1	50
	5 Avatanak	0.4	80
	6 Akun	0.1	10
	7 Akutan	0.2	70
	8 Unalga	0.1	45
	9 Umnak	0.2	50
	10 Samalga	3.9	200
	11 Chuginadak	1.0	210
170°W–175°W			
Herbert Island to Atka Island	12 (Herbert)	4.8	275
	13 (Yunaska)	6.6	457
	14 Chagulak	0.3	65
	15 Amukta	19.3	430
	16 Seguam	2.1	165
	17 Amlia	0.1	25
175°W–180°			
Atka Island to Amchitka Island	18 Atka	0.2	35
	19 (Oglodak)	0.1	5
	20 Fenimore	0.2	35
	21 Tagalak	0.1	35
	22 Chugul	0.6	85
	23 Umak	0.1	20
	24 Little Tanaga	0.1	30
	25 Kagalaska	0.1	25
	26 Adak	0.5	60
	27 Kanaga	0.1	30
	28 Tanaga	3.6	235
	29 (Ogliuga)	0.1	10
	30 (Kavalga)	0.3	55
	31 Amchitka	45.7	1155
180°–173°E			
Amchitka Island to Attu Island	32 Oglala	0.8	25
	33 (Rat)	0.6	15
	34 (Kiska)	6.8	110
	35 Buldir	28.0	640
	36 Semichi	1.7	105
173°E–163°E			
Attu Island to Kamchatka Peninsula	37 (Near)	239	2000[2]
	38 Komandorski	3.5	105[2]
	39 Kamchatka	335.3	4420[2]

[1] Numbers given correspond to those shown in Figure 3. Parentheses indicate that no geographic name has been assigned.

[2] From Udintsev *et al.* (1959). Maximum depth given.

Aleutian Trench

The Aleutian Trench occurs about 170 km south of the Aleutian-Komandorski island chain and is characterized by depths which vary from 5,000 to over 7,000 m. It extends from the Gulf of Alaska to the Komandorski Ridge, near long. 166°E.

The Komandorski Ridge, indicated by the 4,000 m contour, extends over 700 km southward of the Komandorski Islands (Fig. 6). Two prominent features are the Detroit and Klamath Table Mounts, which rise to within 2,814 and 2,770 m, respectively, of the sea surface.

Eastward of long. 175°E, the bottom topography southward of the Aleutian Trench is relatively uniform, with depths of approximately 5,000 to 6,000 m.

DISTRIBUTION OF PROPERTIES

Salinity

Vertical Distribution

Northward of lat. 42°N, an excess of precipitation over evaporation and an extensive runoff from coastal areas result in a surface layer of low salinity. Salinity values increase continuously with depth, and a relatively sharp halocline usually occurs between 75 and 150 m. A striking feature of the salinity structure southward of the Aleutian Islands is the ridging of the isohalines (Fig. 7). This ridging is continuous from the Gulf of Alaska westward beyond long. 171°E.

Surface Distribution

The distribution of surface salinity in the region between the Bering Sea and lat. 46°N shows a pronounced salinity minimum south of the Aleutian Islands, which is caused by the westward advection of dilute coastal water from the Gulf of Alaska by the Alaskan Stream (Fig. 8). Between long. 175°W and

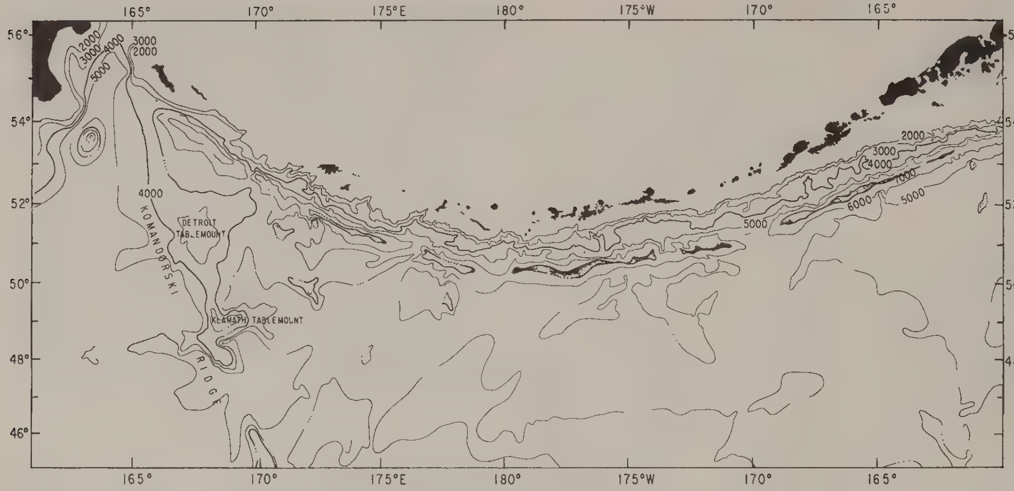


FIGURE 6. Bathymetry southward of Aleutian-Komandorski island chain (depths in meters).

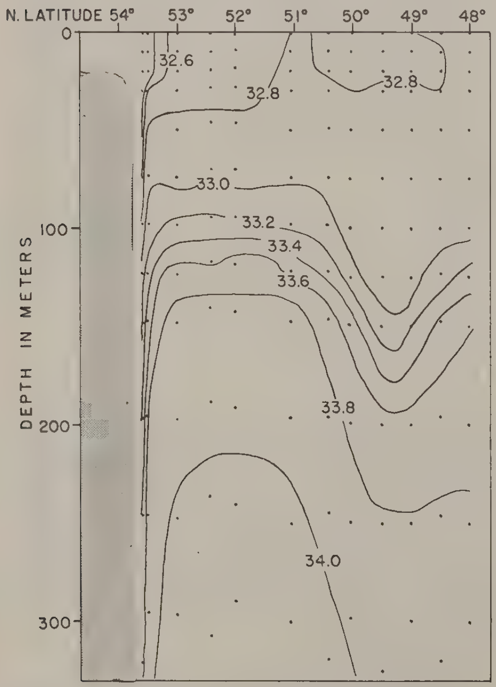
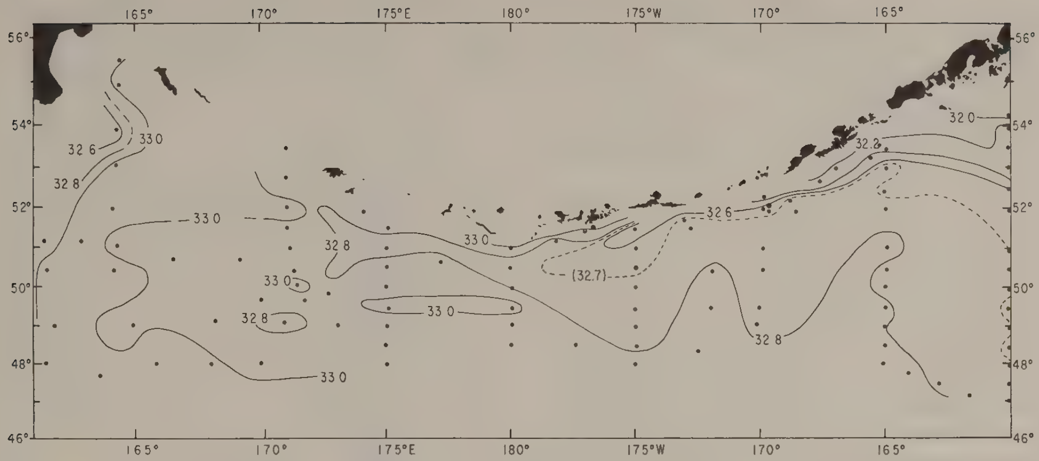


FIGURE 7. Vertical section of salinity (‰) structure at long. 165°W, July 1959 (land shown by stippling).

175°E, the axis of the salinity minimum occurs 50 to 150 km offshore and indicates the absence of any appreciable northward flow through the passes between the Aleutian Islands.

Previous data which are most difficult to reconcile with confinement of the Alaskan Stream southward of the Aleutian Islands were presented by Barnes (1936) and were based upon observations obtained during the cruise of the USS *Gannet* during the period June to August 1933. A significant northward geostrophic flow of approximately 0.3 knot, referred to the 1,000-decibar surface, was reported south of Tanaga Island and the water was shown to flow through Tanaga Pass into Bering Sea. However, the surface salinity in this area was in excess of 33.0‰, which indicates the origin of the water to be the Bering Sea, and the dilute water characteristic of the Alaskan Stream was actually confined well offshore (Fig. 9). A similar surface salinity distribution occurred during 1959 (Fig. 9). Neither the 1933 nor the 1959 salinity data south of Adak Island provide an indication of the abruptness of the front between the Alaskan Stream and water of Bering Sea origin. However, surface observations in this area obtained during August 1963 show a similar surface salinity distribution and a differential of 0.78‰ (33.08 to 32.30) within a 3-mile interval approximately 30 miles south of Adak (Table 2). This indicates that when adequate data are available, the northern boundary of low salinity water characteristic of the Alaskan Stream can be clearly defined, and its location may be found well southward of the Aleutian Islands.

The presence of surface salinities in excess of 33.0‰ south of the Aleutian Islands implies a southward component of surface flow from the Bering Sea through one or more passes, which may or may not flow north-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33 0

Figure 8. Distribution of surface salinity (‰), summer 1959.

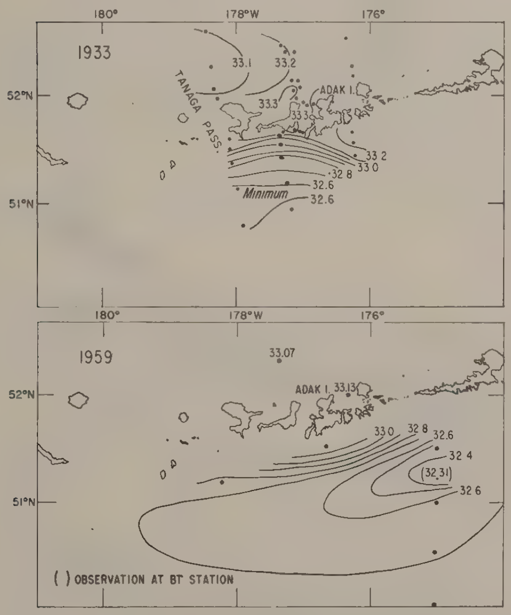
ward again through an adjacent pass.

Temperature

Vertical Distribution

Although the vertical salinity distribution in the central Pacific Ocean north of lat. 42°N exhibits no inversion, the temperature structure is characterized by both a minimum and maximum stratum. The temperature-minimum stratum is characterized by two cold cores. One exists at 75 to 125 m and is the result of local seasonal overturn and subsequent heating of the surface layer; it is usually located in the shear zone between the Alaskan Stream and Subarctic Current. The other occurs at approximately 200 to 300 m, and is caused by seasonal overturn in Bering and Okhotsk Seas where the presence of ice permits vertical mixing to a greater depth. This cold water (0°C) is advected eastward in the Subarctic Current, and by the time it reaches the central Pacific Ocean there may be little difference in temperature between it and the shallower cold core caused by local conditions.

The temperature-maximum stratum occurs immediately below the minimum stratum. Temperatures greater than 4.0°C are found over 200 km southward of the Aleutian Islands at a depth of approximate-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32 8
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Figure 9. Surface salinity (‰) near Adak Island, 1933 and 1959.

Table 2. Surface salinity (‰) south of Adak Island, August 1963.

Data	Time	Lat. N	Long. W	Salinity (‰)
8/10	1745	51°42′	176°24′	33.04
8/10	1830	51°36′	176°22′	33.04
8/11	1800	51°15′	176°33′	33.08
8/11	1830	51°12′	176°26′	32.30
8/12	1600	51°02′	176°17′	32.28
8/12	1630	50°57′	176°17′	32.31
8/12	1700	50°52′	176°15′	32.34
8/12	1800	50°44′	176°17′	32.34
8/12	1830	50°49′	176°19′	32.34
8/12	1900	50°36′	176°18′	32.36

ly 150 m (Fig. 10). Plakhotnik (1964) has reported the presence of this warm water stratum in the Gulf of Alaska during winter and summer as a relatively permanent feature.

Continuity of these two features can be shown by the distribution of temperature in the temperature-minimum stratum and by the maximum temperatures below the minimum stratum.

Temperature-Minimum Stratum

Several features are evident in the distribution of minimum temperatures (Fig. 11). Temperatures in the northwestern Pacific are several degrees lower than those in the northeastern Pacific Ocean. There is a sharp discontinuity between long. 160°W and long. 165°W near lat. 53°N, and again at long. 165°E near lat. 51°N. The first discontinuity is believed to be associated with the Gulf of Alaska gyre. The second discontinuity is considered to denote the western terminus of the Alaskan Stream. Between lat. 47°N and lat. 50°N, an eastward intrusion of cold water (lower than 3.4°C) extends across the area considered, marking the approximate location of the northern boundary of the Subarctic Current. Finally, there is a discontinuity of isotherms greater than 4°C along the Aleutian Islands; however, isotherms in the temperature-maximum stratum which exists immediately below the temperature-minimum stratum are continuous, implying continuity of the westward flow along the island chain.

Temperature-Maximum Stratum

The distribution of temperature in the temperature-maximum stratum (Fig. 12), suggests continuity of the warm water flowing out of the Gulf of Alaska to long. 171°E and, except for the discontinuity at this longitude which may be due to inadequate sampling rather than to any physical process, it may be considered to

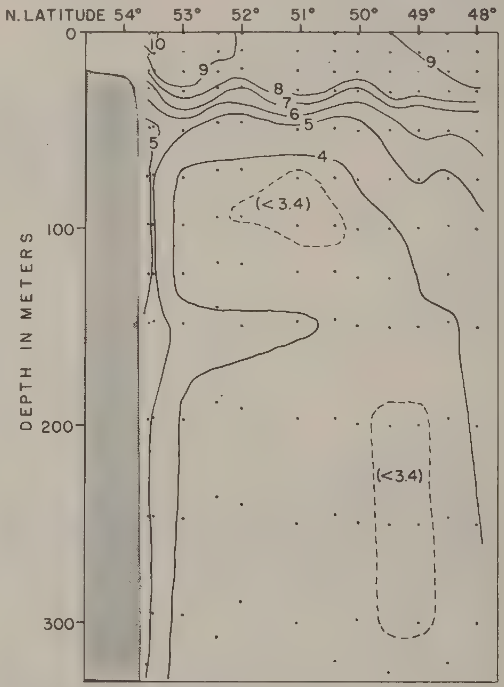

FIGURE 10. Vertical section of temperature (°C) structure at long. 165°W, July 1959 (land shown by stippling).

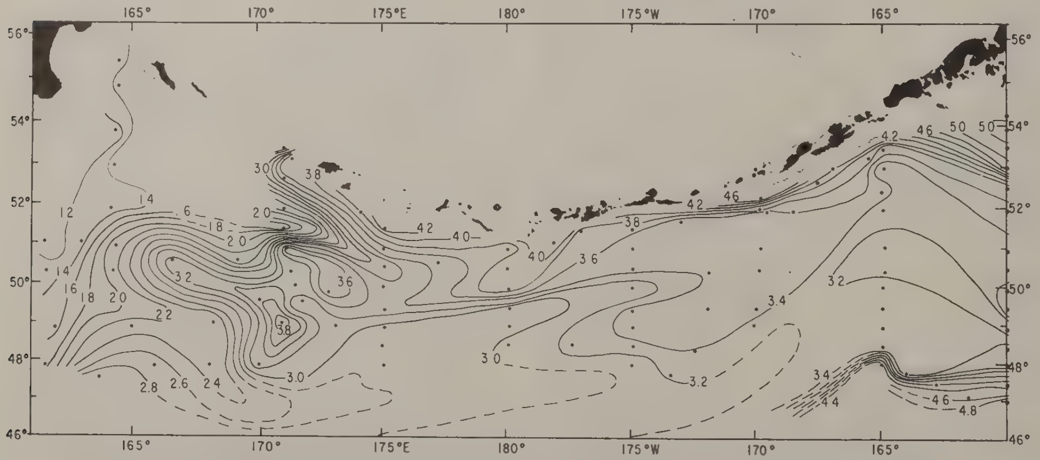

FIGURE 11. Distribution of temperature (°C) in the temperature-minimum stratum, summer 1959.

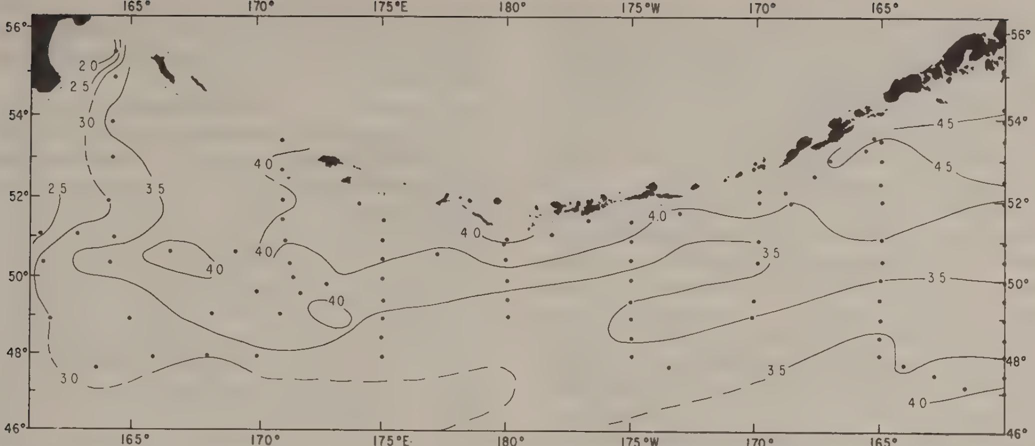
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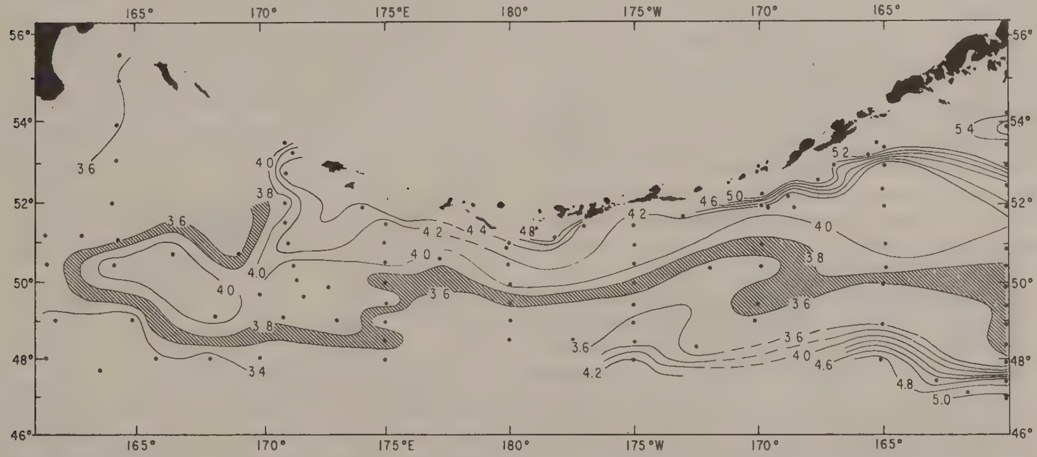
FIGURE 12. Distribution of maximum temperatures (°C) below the temperature-minimum stratum, summer 1959.

extend to approximately long. 162°E. However, the possibility of warm water eddies being pinched off and existing in this area as separate entities cannot be discounted. Also clearly apparent is a tongue of cold water (lower than 3.5°C) south of lat. 51°N which extends from the western Pacific to long. 160°W.

Temperature Distribution on Sigma-t Surface 26.90

To minimize some of the problems involved in interpreting temperature distributions affected by extensive vertical mixing, we can consider the temperature distribution below the depth of seasonal influence. The sigma-t surface 26.90, which is located at a suitable depth to serve our purpose, was selected. In the absence of evidence to the contrary, we may assume that mixing occurs primarily along, rather than normal to, such a surface. The surface selected is an undulating one, usually found between 200 and 400 m throughout the Subarctic region. It commonly lies above 300 m in the Aleutian area, and flow of water of this density could take place through some passes: Samalga (10), Chuginadak (11), Herbert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3.6
3.6
3.6
4.0
4.2
4.6
4.8
5.0

FIGURE 13. Distribution of temperature (°C) on sigma-t surface 26.90, summer 1959. Shaded area shows the approximate southern boundary and western extent of the Alaskan Stream as indicated by temperature distribution.

(12), Yunaska (13), Amukta (15), Tanaga (28), Amchitka (31), Buldir (35), and the remaining western passes, Near (37) and Komandorski (39). However, the 4°C isotherm is continuous from long. 160°W to the westward of long. 170°E (Fig. 13). The approximate location of the boundary between the Subarctic Current and the Alaskan Stream is between the 3.6°C and 3.8°C isotherms.

Analysis of data collected north of the Aleutian Islands during 1959 does not show temperatures in excess of 4°C on the sigma-t surface 26.90. Maximum temperatures are near 3.8°C and are found to extend from long. 171°E to 170°W. It is impossible to ascertain if there is a northward flow through all passes, with a slight lowering of temperature caused by mixing in the passes, or if the main flow is northward only through the western passes, with subsequent eastward advection of this water type along the north side of the Aleutian Islands. Either condition could cause the temperature distribution found on the north side of the island chain.

CURRENTS

The measurement of absolute currents in the ocean is a difficult and important problem. The choice among various proposed theories of ocean circulation may depend upon a comparison of theoretical results with observed ocean currents. As Stommel (1960) says in the concluding sentence of *The Gulf Stream*, "Many of the hypotheses suggested have a peculiar dreamlike quality, and it behooves us to submit them to especial scrutiny and to test them by observation."

Current velocities may be obtained either directly by a metering device or by tracing techniques, or indirectly by analysis of distribution of properties. Direct current observations are difficult to obtain. Fomin (1964) has described some of the obstacles in obtaining direct current measurements. He also presented the qualifications which must be attached to the use of currents calculated by indirect methods. Indirect methods, in general, can provide information only about relative currents, not absolute currents. However, in many parts of the world ocean, indirect methods are the only expedient method of obtaining currents and circulation.

In the Aleutian area the only direct current measurements prior to 1959 appear to have been made in the island passes. The United States Coast Pilot 9—Alaska (U.S. Department of Commerce, 1955) states:

> In the past, numerous reports have been received to the effect that the flood currents flowing into the Bering Sea are very much stronger than the ebb currents. These reports have been largely discounted by observations in a number of passages which in general reveal equally strong ebb currents flowing through the passes from the Bering Sea. It is believed that on account of the large diurnal inequality in the current of this region, mariners have been deceived by the long periods of flood currents that occur near the times of the moon's maximum declination.

Both direct current observations obtained by drogue and vessel drift, and relative current observations obtained by use of the geostrophic approximation, are used to describe the currents and transport in the Alaskan Stream.

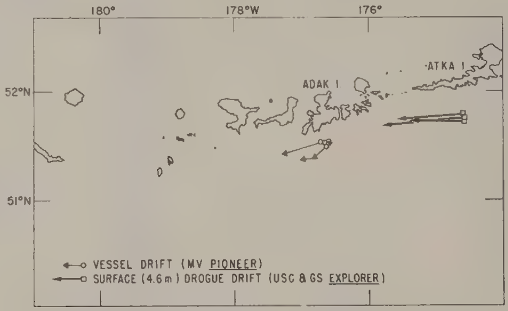
180°
178°W
176°
52°N
51°N
ATKA I
ADAK I
VESSEL DRIFT (MV PIONEER)
SURFACE (4.6 m) DROGUE DRIFT (USC & GS EXPLORER)

FIGURE 14. Drift of MV *Pioneer* during three consecutive nights (July 26–29, 1959) and drift of parachute drogues (4.6 m depth) released and tracked by USC & GS vessel *Explorer* (June 1959).

DIRECT CURRENT DATA

Drift of MV Pioneer

The set and drift of the MV *Pioneer* were recorded on three consecutive nights at approximately the same time and position south of Adak Island (Fig. 14). During each period, the vessel was moored to about two miles of gillnet. Wind speeds varied from less than 5 m/sec to calm and are not considered to have appreciably affected the vessel's drift, although a small Ekman component may have been present. Maximum drift during an approximate 6-hour period was

TABLE 3. Drift and set of MV *Pioneer* south of Adak Island, July 1959.

Date	Zone time	Lat. N	Long. W	Period (hrs)	Drift (km)	Direction (°T)	Speed (cm/sec)
7/26	1820	51°31′	176′22′				
7/27	0715	51°27′	177°01′	12.9	23	252	50
7/27	1307	51°25′	177°16′	5.9	18	258	85
		Resultant		18.8	41	254	60
7/27	1810	51°31′	176°40′				
7/28	0710	51°29′	176°39′	13	4	163	10
7/28	1815	51°29′	176°38′				
7/29	0705	51°22′	176°49′	12.8	18	226	40
7/29	1215	51°22′	176°58′	5.2	11	270	55
		Resultant		18.0	27	241	40

in excess of 80 cm/sec, and during two periods an average velocity of about 50 cm/sec in a westerly direction occurred (Table 3).

U.S. Coast and Geodetic Survey Drogue Studies

Current measurements by the USC&GS *Explorer* south of Atka Island during June 1959 also indicated a swift westerly flow. Six parachute drogues, three shallow (4.6 m) and three deep (300 m), were released and tracked for over 24 hours. Drogue positions were recorded every two or three hours. The three shallow, or surface, drogues moved at an average velocity of about 75 cm/sec, 270°T (Fig. 14). Maximum speeds in excess of 100 cm/sec were recorded. One of the deep drogues grounded, but the other two moved at an average velocity of over 50 cm/sec, 270°T. The trajectories of all drogues were essentially straight line paths and no evidence of north-south tidal currents was found.

Japanese Drift Floats

Taguchi (1959) conducted an extensive drift float experiment in the western Pacific Ocean during the period in which the oceanographic data under discussion were obtained. Hooks attached to floats facilitated capture in gillnets set each night by the extensive Japanese fishing fleet. The release and recovery points of selected floats (Fig. 15) suggest that the westward surface flow in this area terminates at long. 165°E and that there is a northward surface flow into the Bering Sea west of Attu Island. The presence of the Komandorski Ridge at long. 166°E may affect the flow in this area.

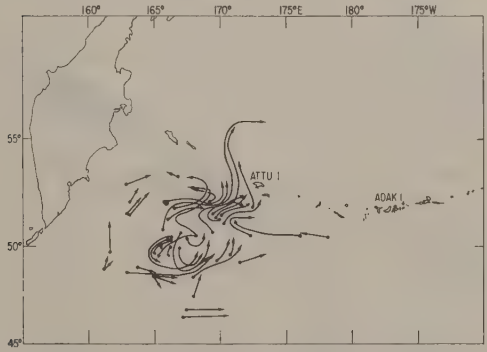

Figure 15. Release and recovery points of selected drift floats, May to July 1959 (adapted from Taguchi, 1959).

Relative Currents

The dynamical method permits calculation of relative currents from the distribution of mass, assuming: synoptic data, a balance between the pressure gradient and Coriolis forces, unaccelerated flow, no friction, and a known reference level of no-net-motion. In the absence of *a priori* knowledge of the reference level only velocities relative to the velocity on an arbitrary selected surface are obtained, rather than absolute values.

The dynamic topographies have been calculated from the modified hydrostatic equation:

$$\Delta D = \int_{p_1}^{p_2} \delta \, dp$$

where ΔD=geopotential anomaly, δ=specific volume anomaly, and dp=pressure differential.

The component of relative velocity normal to the line between two stations, A and B, has been computed using the equation:

$$v = \frac{10(\Delta DA - \Delta DB)}{L \, 2\omega \sin \phi}$$

where v=velocity, ΔD=geopotential anomaly, L=distance between stations, ω=angular velocity of earth (0.729×10^{-4} rad/sec), and ϕ=mean latitude of the stations.

Relative surface currents based on a reference level of 300 m will be considered first, since data from almost all stations extend to this depth. Although these data are not synoptic, they were obtained over a relatively short period of time. The observed values have been used and no attempt has been made to adjust the data to a mean time period, thereby accounting for seasonal heating, as this would not significantly alter the dynamic topography or the conclusions.

Although the distribution of properties makes it appear reasonable that a reference surface of no-net-motion must lie below 300 m, the major speed changes occur in the upper layers and the 0/300 m dynamic topography indicates the dominant features of the circulation.

Dynamic Topography, 0/300 m

As might be expected in a shear zone between two opposing currents, a number of eddies or gyres are suggested by the surface topography, but the limited data, and location and time of sections make it impossible to define the actual extent of each gyre (Fig. 16). Although the 0.440 dynamic meter surface is present from long. 180° to 160°W, it appears discontinuous at several locations. Thus, the 0.460 dynamic meter surface has been used to indicate the northern boundary of the eastward flow south of lat. 51°N, and the southern boundary of the westward flow between lat. 51°N and the Aleutian Islands. The former is the Subarctic Current and the latter is the Alaskan Stream.

There is a general continuity of westward flow in the Alaskan Stream between long. 160°W and 170°E. At long. 170°E the flow turns northward and its effect on the two gyres at long. 171°E and 167°E near lat. 50°N is not readily apparent.

Dynamic Topography, 300/1,000 m

Not all stations extend to 1,000 m, but analysis of the flow at 300 m relative to 1,000 m from the data available also shows the eastward and westward flows described in the previous section, south and north of a clearly defined trough. This indicates that the readjustment of mass extends well below the depth of seasonal influence, which has been shown to be approximately 100 to 150 m (Dodimead *et al.*, 1963). It also implies that the current systems must be relatively permanent.

Dynamic Topography, 0/1,000 m

Because extreme gradients are not found below 300 m, it is believed that data from the coarse grid of stations that extends to 1,000 m adequately define the 300/1,000 m topography, and the 0/300 m topography has been superimposed upon that of 300/1,000 m to give the 0/1,000 m topography (Fig. 17). The continuity of the westward flow in the Alaskan Stream from long. 160°W to long. 170°E is clearly evident. The cyclonic gyre near lat. 50°N, long. 172°E, is more clearly defined, and the validity of the circulation pattern in this area, which indicates a divergence of the Alaskan Stream, is reinforced by the drift float study discussed in the section on direct current data.

The maximum relative speeds, about 30 cm/sec, occurred between *Tordenskjold* Station Nos. 77 and 76 (long. 160°W). Generally, speeds of about 10 cm/sec were calculated for the Alaskan Stream.

TRANSPORT

Geostrophic surface currents relative to 1,000 m have been used to indicate the magnitude of the Alaskan Stream and to mark its boundaries. To describe completely the Alaskan Stream, it is necessary to specify not only the general extent of the current system, but to provide absolute currents and mass transport, and to relate the Alaskan Stream to the general pattern of circulation in the North Pacific Ocean.

Relative Transport

The calculation of relative transport requires a knowledge of the internal distribution of currents in the water column. Relative transport calculated from the observational data by integrating the relative velocities will be considered as a first approximation to the transport in the Alaskan Stream. These calculations are subject to the same qualifications mentioned in the discussion of relative currents, with somewhat more uncertainty than the current speeds, since any error in the reference velocity will be integrated over the water column.

The necessity of occupying station positions according to a predetermined plan introduces another factor which may reduce the apparent observed relative transport below its true value. To obtain the maximum value of the geostrophic transport, data must be obtained at both boundaries of the system,

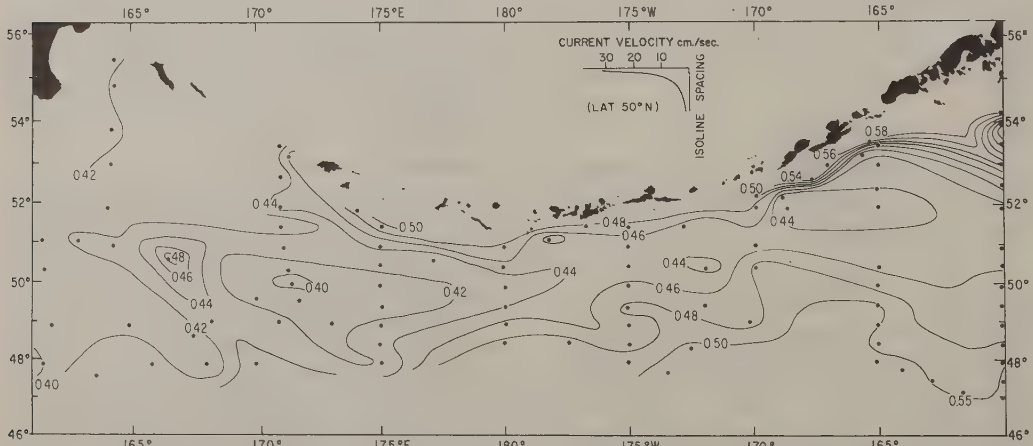

Figure 16. Dynamic topography, 0/300 m, summer 1959.

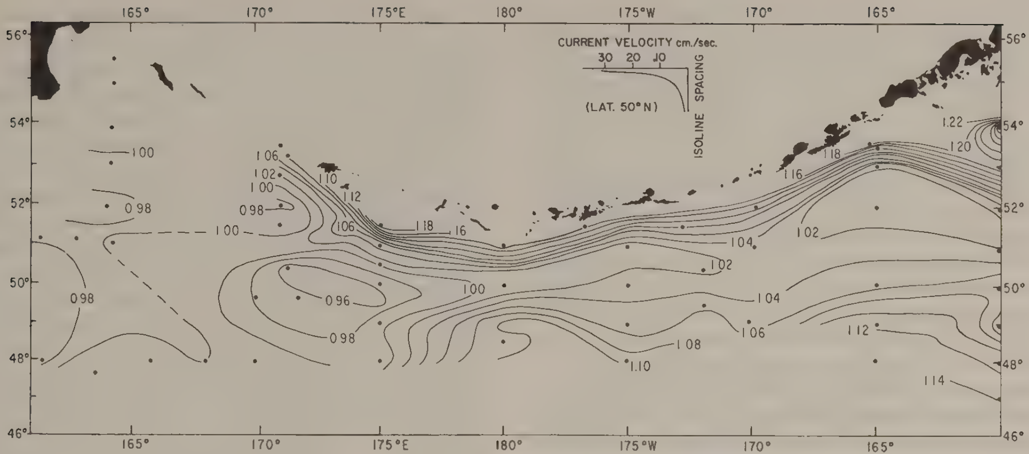
165°
170°
175°E
180°
175°W
170°
165°
56°
54°
52°
50°
48°
46°
CURRENT VELOCITY cm./sec.
30 20 10
(LAT. 50°N)
ISOLINE SPACING
1 00
0 98
1 06
1 02
1 00
0 98
1 00
1 10
1 12
1 06
1 18
1 16
1 04
1 02
1 02
1.22
1 20
1 18
1 16
0 96
0 98
1 00
1 04
1 06
1 08
1.10
1 12
1 14
0 98

Figure 17. Dynamic topography, 0/1000 m, summer 1959.

Table 4. Dynamic anomalies at stations used for computations of volume transport[1].

	Long. 160°W		Long. 165°W		Long. 170°W		Long. 175°W	
Depth (m)	Stn. T–77	Stn. T–71	Stn. T–48	Stn. T–52	Stn. T–44	Stn. T–46	Stn. P–69	Stn. P–73
0	0	0	0	0	0	0	0	0
30	.092	.083	.087	.076	.077	.070	.055	.080
50	.146	.130	.137	.118	.122	.112	.090	.124
75	.206	.178	.194	.166	.174	.161	.132	.172
100	.262	.220	.246	.208	.221	.207	.173	.215
150	.365	.289	.339	.276	.302	.287	.253	.286
200	.454	.345	.425	.332	.372	.406	.331	.343
300	.590	.449	.574	.436	(.496)	.458	.479	.447
400	(.699)	.547	(.684)	.532	(.606)	.557	(.602)	.544
500	(.800)	.639	(.784)	.621	(.706)	.650	(.709)	.633
600	(.895)	.725	(.879)	.705	(.801)	.737	(.807)	.717
800	(1.072)	.880	(1.057)	.861	(.979)	.894	(.986)	.871
1000	(1.231)	1.020	(1.216)	1.003	(1.138)	1.035	(1.142)	1.012

	Long. 180°		Long. 175°E		Long. 171°E			
Depth (m.)	Stn. T–8	Stn. T–10	Stn. P–62	Stn. P–10	Stn. O–16	Stn. P–19	Stn. P–18	Stn. P–16
0	0	0	0	0	0	0	0	0
30	.057	.063	.068	.054	.062	.057	.057	.057
50	.092	.102	.105	.090	.100	.092	.095	.094
75	.134	.148	.148	.134	.142	.131	.141	.137
100	.176	.190	.189	.176	.183	.169	.184	.175
150	.257	.261	.269	.245	.262	.238	.260	.239
200	.334	.321	.347	.301	.335	.298	.324	.293
300	.478	.428	.493	.405	.461	.406	.432	.393
400	.601	.526	.617	.500	.571	.505	(.531)	(.486)
500	.708	.618	.727	.589	.672	.597	(.623)	(.573)
600	.806	.705	.829	.672	.762	.684	(.710)	(.656)
800	.985	.865	1.015	.824	.928	.843	(.869)	(.808)
1000	1.141	1.008	1.181	.959	1.084	.986	(1.012)	(.945)

[1] P=*Pioneer*, T=*Tordenskjold*, O=*Oshoro Maru*; see Figure 2.

Parentheses around station data indicate values obtained from adjoining stations which extended to 1000 m, and had similar properties at 200 and 300 m.

the geopotential along the crest and trough of the topography. Otherwise, the section may contain opposing flow and considerably reduced transports would result. Because stations were occupied at predetermined positions, precise values have not been obtained for the entire stream across all sections, but the close station spacing has provided a good continuity of transport across the previously discussed north-south sections. Serial dynamic anomalies are listed for reference (Table 4).

Relative volume transports have been computed using the following equation from Sverdrup *et al.* (1942, p. 463):

$$T = L\int_0^d v\,dz = 10c\int_0^d (\Delta D_A - \Delta D_B)\,dz$$

where T=relative volume transport, L=distance between stations A and B, v=geostrophic velocity, dz=depth increment, $c = 1/2\,\omega \sin\phi$, and ΔD=geopotential anomaly.

Transport, 0 to 1,000 m

Since geopotentials are essentially streamlines for geostrophic flow, the dynamic topography shown (Fig. 17) indicates the flow pattern which may be expected at the surface in the Alaskan Stream. Since the topography at intermediate depths with respect to 1,000 m is similar to that at the surface, the integrated transport pattern will also be similar to the surface dynamic topography. Stations have been selected which are located approximately along the same geopotentials (1.02 and 1.14 dynamic meters), and geostrophic volume transports have been calculated for the sections between the stations (Fig. 18).

Transport in the Alaska Current, which moves cyclonically around the periphery of the Gulf of Alaska, is based on the 1000-m reference level and is usually 10×10^6 m³/sec. Calculations based upon data from the HMCS *Oshawa* (Fisheries Research Board of Canada, 1959), show that in 1959 the westward transport in the northern part of the Gulf of Alaska was 9.8×10^6 m³/sec. The westward transport across long. 165°W of 5.9×10^6 m³/sec indicates that 3.9×10^6 m³/sec had returned southward to the Gulf of Alaska gyre eastward of this longitude (a loss of 2.5×10^6 m³/sec occurs between long. 160° W and 165° W). This southward flow is evident in the dynamic topography (Fig. 17).

The relatively small transport values across the north and south boundaries westward of long. 165°W are probably related more to station position than actual flow. An east-west transport of 6×10^6 m³/sec occurs between long. 165°W and 175°E. No opposing transport is observed until long. 171°E where an eastward intrusion results in a divergence of flow. Lack of data to 1,000 m and inadequate station locations west of long. 171°E make any presentation of transport based on dynamic topography unreliable beyond this location.

WIND-DRIVEN TRANSPORT

The relative transport calculated by the geostrophic approximation provides no information about the cause of the Alaskan Stream, or its relation to the general circulation in the North Pacific Ocean. The assumptions used in reducing the relative transports to absolute values are essentially facts observed about the stream itself, and the true transports still do not

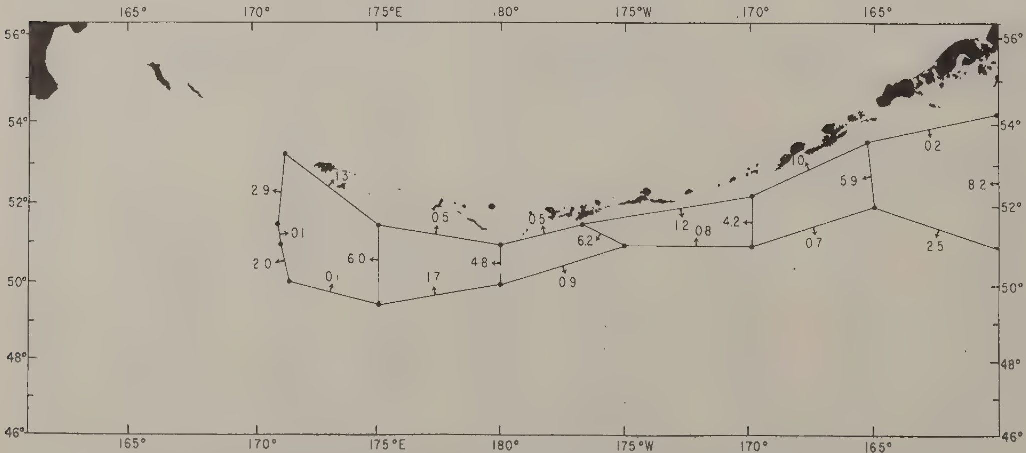

FIGURE 18. Relative transport (m³/sec × 10⁶) in the Alaskan Stream, 1959.

provide an indication of the forces that cause the Alaskan Stream.

Some insight into the reasons for the stream appearing as it does can be obtained by consideration of the transport of vorticity within the stream. Since the stream is bounded on both sides by lines of zero velocity, it will contain no relative vorticity and transport no relative vorticity. Separate regions within the stream can, and of course will, possess relative vorticity, but the net relative vorticity across the stream must be zero, regardless of the distribution of vorticity within the stream.

The observed stream moves from higher latitudes to lower latitudes, that is from regions of higher to lower planetary vorticity. Therefore, the total counterclockwise vorticity of the stream is reduced in the direction of the flow. The stream thus serves the function of removing counterclockwise vorticity from the ocean, and the observed features of the stream result from the manner in which the vorticity is removed. An intuitive picture of how this takes place can be presented. As the stream begins to flow southward, the released planetary vorticity appears as an increase in the counterclockwise relative vorticity. Since the stream cannot transport any relative vorticity, this may be compensated for by a production of clockwise relative vorticity produced by a shrinking of the stream. This process will continue until the stream has deepened, narrowed, and increased in velocity such that the friction on the inshore side is great enough to add enough clockwise vorticity to the stream to compensate for the counterclockwise relative vorticity being exchanged from the planetary vorticity. Under these conditions the flow will become steady. Actual values for the distribution of depth, width, and velocity in the stream will depend upon such factors as: the density of the water available for the stream, density of the water through which the stream passes, rate of change of planetary vorticity, the nature of the frictional forces, and the means by which the vorticity is diffused across the stream. The relations which obtain among these factors in the Alaskan Stream are complex and not exactly known. Certain qualitative features may, however, be deduced for the steady stream. As vorticity is introduced at the land boundary, we would expect the greatest shear to take place there, and the cross-stream velocity profile to be asymmetric, with the axis strongly shifted towards the shore. The reference depth will vary from the surface on the interior boundary of the stream to some maximum value near the axis. These features are observed in the Alaskan Stream.

The curl of the wind stress changes sign at about lat. 50°N in the eastern North Pacific Ocean (Fofonoff, 1961), such that for latitudes north of lat. 50°N the effect of the curl of the wind stress is to add counterclockwise relative vorticity to the water. However, since the relative vorticity is negligible, and the water in a major ocean basin is constrained from shrinking by its boundaries, it must turn northward into regions of larger counterclockwise planetary vorticity. If the initial basis for the stream is to provide a physical means of removing vorticity which has been added to the North Pacific Ocean by the wind, then the observed transport in the Alaskan Stream should balance the northward component of the wind-driven circulation in the eastern North Pacific Ocean.

The magnitudes of the transport field of the local wind near the Aleutian Islands, and the wind-driven transport in the eastern North Pacific Ocean were investigated to see if the Alaskan Stream may properly be considered as a return flow for the wind-driven transport. Due to the lack of wind data from the Aleutian region, it was necessary to rely on sea level pressures and calculate the transports from the mean pressure field. The method of Fofonoff (1961) was followed, but extended to obtain more detailed information.

Sea Level Pressure and Wind Stress

The month of July was selected as the mean time period of the oceanographic data; sea level pressures and winds during July 1959 were derived from 6-hourly weather maps furnished by the Seattle Office of the U.S. Weather Bureau. A relationship between the pressure and wind was obtained using observed wind vectors in the vicinity of lat. 45°N to 50°N, long.

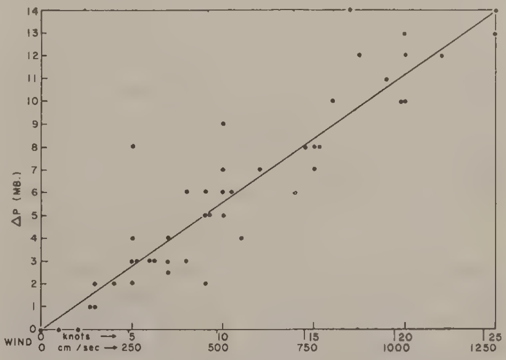

Figure 19. Relationship between east-west component of surface winds (rotated 15° to the right of the downwind direction) *versus* north-south sea-level pressure gradient in the vicinity of lat. 45°N–50°N, long. 180°–170°W, July 1959.

180° to 170°W. These vectors were rotated 15° to the right of the surface downwind direction so that they paralleled the isobars, and the resolved zonal components were then plotted against the respective north-south pressure gradient between two grid points. Since most of the weather data are derived from widely spaced and intermittent ship reports, a large scatter was present; however, a general linear relationship was obtained (Fig. 19).

Sea level pressure grid points presented by Fofonoff (1961) were considered too widely spaced to be effective in determining the effect of local wind stress in the narrow region of the Alaskan Stream. Values of sea level pressure at 38 grid points, separated by 5° of latitude and longitude, were interpolated from each 6-hour chart for July 1959. Average weekly, biweekly, and monthly pressure distributions were drawn to determine if any unusual conditions occurred in the Aleutian area that might have been masked. None were apparent, and the detailed chart of mean sea level pressure for July and the locations of the grid points are shown in Figure 20.

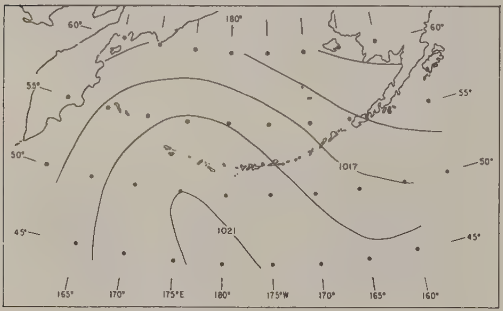
60°
180°
60°
55°
55°
50°
1017
50°
45°
1021
45°
165°
170°
175°E
180°
175°W
170°
165°
160°

FIGURE 20. Mean sea level pressure during July 1959, determined from the average of pressures shown on 6-hour weather charts at the indicated grid points (contour interval 2 mb).

The resulting pressure distribution is almost identical to that presented by Fofonoff (1961) for July 1959. The general stress law:

$$\tau = \rho \gamma^2 v^2$$

(where τ=surface wind stress, dynes/cm²; ρ=density of air, 1.22×10^{-3} gm/cm³; γ^2=non-dimensional drag coefficient taken as 1.9×10^{-3} for an average wind speed of 13 m/sec (Deacon and Webb, 1962, p. 57); and v=wind speed in cm/sec) has been used to compute wind stress and the monthly sea level pressures have been used to represent winds. Introduction of the mean monthly pressure produces an error when the above stress law is utilized because the monthly root-mean-square of the individual daily mean usually will not be equal to the square of the monthly mean. The magnitude of this error was investigated. Daily 6-hour pressure gradients between meridional grid points were averaged, squared, and summed for the month. The monthly root-mean-square values of pressure gradients between north-south grid points were summed to establish the new pressure field. The resulting root-mean-square pressure field (Fig. 21) shows a considerable increase in the pressure gradients from that computed using mean monthly pressures determined from 6-hourly observations.

The validity of the relationship between the wind speed and pressure gradient can be supported by 6-hourly observations of wind at a shore station. The monthly root-mean-square wind velocity vector at Adak Island (long. 178°W) for July 1959 gives a resultant wind of 8.2 knots from the southwest, the wind from the root-mean-square pressure field between lat. 50° and 55°N at this longitude is a 7.0 knot westerly wind. The wind speeds are in good agreement. Lack of exact agreement in wind direction may have

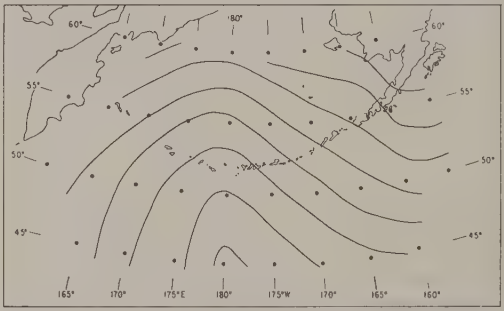
60°
180°
60°
55°
55°
50°
50°
45°
45°
165°
170°
175°E
180°
175°W
170°
165°
160°

FIGURE 21. Root-mean-square sea level pressure field, July 1959 (contour interval 2 mb).

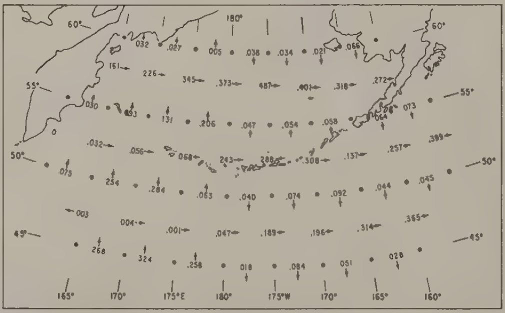
60°
180°
60°
032
.027
005
.038
.034
.021
.066
161
226
345
.373
487
.401
.318
.272
55°
55°
030
93
131
.206
.047
.054
.058
064
073
0
.032
.056
.068
243
288
.308
.137
.257
.399
50°
50°
.075
254
.284
.063
.040
.074
.092
.044
.045
003
004
.001
.047
.189
.196
.314
.365
45°
45°
268
324
.258
018
.084
051
028
165°
170°
175°E
180°
175°W
170°
165°
160°

FIGURE 22. Zonal and meridional components of wind stress (dynes/cm²), July 1959.

been caused by the mountainous topography of Adak Island in the vicinity of the reporting station.

The zonal (τ_x) and meridional (τ_y) wind stresses between grid points were computed by including a factor, K (K=1.00 at lat. 47.5°N, 0.93 at lat. 52.5°N, and 0.88 at lat. 57.5°N), in the relationship between wind velocity and pressure gradient ($v\alpha\Delta p$) to compensate for the latitudinal change in Coriolis parameter from the location the relationship was obtained (lat. 45°N to 50°N) and by rotating the wind 15° to the left of the downwind direction of the pressure distribution (Fig. 22).

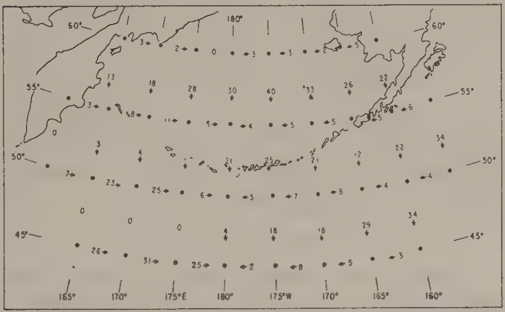

FIGURE 23. Zonal and meridional components of Ekman transport (m³/sec/km × 10), July 1959.

Ekman Transport

The Ekman transport has been derived directly from the wind stress and Coriolis parameter. Zonal and meridional Ekman transports in units 10 m³/sec/km were derived (Fig. 23) using the relations:

$$U=\frac{\tau_y}{f} \text{ and } V=-\frac{\tau_x}{f}$$

where U, V=zonal and meridional components of Ekman transport, respectively; τ_x, τ_y=zonal and meridional components of wind stress, dynes/cm², respectively; and j=Coriolis parameter, rad/sec.

An interesting feature of the results is that all significant meridional components are to the south. In the vicinity of the Aleutian passes, maximum transport occurs between long. 170°W and 180°. Considering the total meridional transport, a southward transport of approximately 0.09×10^6 m³/sec is obtained between these two longitudes. This is about an order of magnitude less than the transport indicated by the distribution of mass. However, it could be significant in confining the Alaskan Stream southward of the island chain. Another significant result is that, in general, components of Ekman transport in the vicinity of the Alaskan Stream are very small in comparison to the transports of 6×10^6 m³/sec obtained from the distribution of mass.

Total Transport

Total transport is a function of the curl of the wind stress which may be expressed as:

$$\text{curl}_z\,\tau = \delta\tau_y/\delta_x - \delta\tau_x/\delta_y.$$

The zonal wind stress gradient, $\delta\tau_x/\delta_y$, was found at each grid point by taking the difference between the values of τ_x immediately north and south of the grid points. The meridional wind stress gradient, $\delta\tau_y/\delta_x$, is obtained in a similar manner, in the east-west direction, but this component must be adjusted because of the northward convergence of the meridians. The following factors were used: lat. 45°N—1.409, lat. 50°N—1.551, lat. 55°N—1.739, lat. 60°N—1.997. Subtraction of the two values at each grid point gives the value of $\text{curl}_z\tau$ (Fig. 24).

The southern boundary of the Alaskan Stream has been shown to be a region of low flow. Assuming the boundary may be approximated by the latitude circle, 50°N, meridional components of total mass transport may be computed between grid points along this circle using the following relationship:

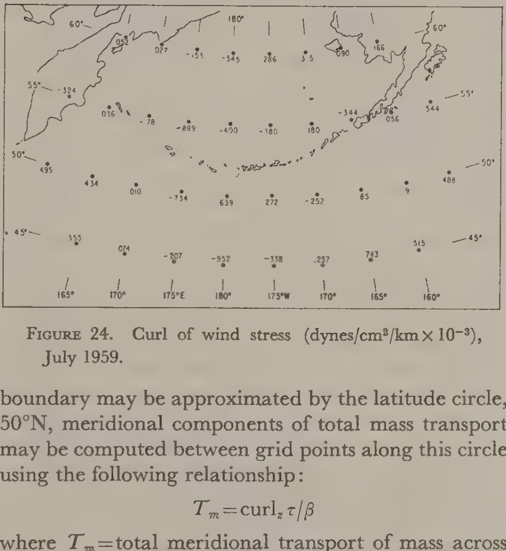

FIGURE 24. Curl of wind stress (dynes/cm²/km × 10^{-3}), July 1959.

$$T_m=\text{curl}_z\,\tau/\beta$$

where T_m=total meridional transport of mass across a unit length of a latitude circle, and β=rate of variation of Coriolis parameter along a meridian.

The effects of local wind stress on the Alaskan Stream may be ascertained by considering the island chain as a solid boundary and the transport across long. 155°W to be zero. Then integrated transports resulting from curl of the local wind stress can be obtained by continuity principles (Fig. 25). A westward transport is obtained from long. 155°W to long. 175°W which has a maximum of 1.5×10^6 m³/sec at long. 165°W. Between long. 170°E and 180° an

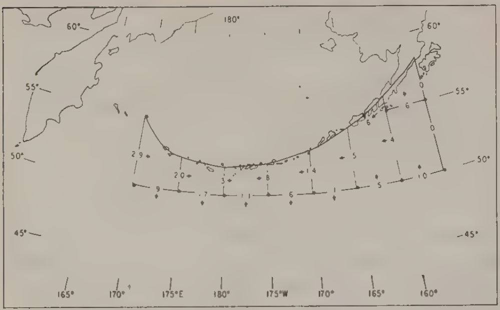

Figure 25. Integrated total transports (m³/sec × 10⁶) from local wind stress, July 1959.

eastward transport is present which has a maximum of 2.9 × 10⁶ m³/sec at long. 170°E.

In order to determine the total integrated transport in the Alaskan Stream, a value for total integrated transport across long. 155°W between lat. 50°N and the Alaska Peninsula is required. This has been computed by Fofonoff (1961, p. 140) and is 5.2×10^{-6} m³/sec. If this boundary value is used, instead of zero as above, the total integrated transport south of the Aleutian Islands is found to reach a maximum of 6.7 × 10⁶ m³/sec at long. 165°W and to gradually decrease to 2.3 × 10⁶ m³/sec at long. 170°E (Fig 26).

Comparison of Theoretical and Relative Transports

The relative transport has been computed from the geostrophic approximation, and thus cannot be compared with the theoretical total transport obtained from the wind stress until the effect of the Ekman transport is considered. If we now define geostrophic transport as that part of the wind-driven transport which will appear associated with a distribution of mass, the meridional component of the geostrophic transport across a latitude circle is equal to the meridional component of total transport minus the meridional component of Ekman transport. Since the maximum Ekman transport between any of the 5° longitudinal segments indicated along lat. 50°N has been calculated to be 0.09 × 10⁶ m³/sec (based on Fig. 23), the direction of meridional geostrophic transport across any of these segments is the same as that indicated by the total transport, and the values are not significantly changed. Thus, the zonal components of geostrophic transport may be considered equivalent to the zonal components of total transport and may be compared directly to the relative transport calculated from the observed distribution of mass.

West of long. 180° the zonal geostrophic transport induced by local wind stress opposed the westward flowing Alaskan Stream (Fig. 25). Reasonably good agreement between these two transports is evident by comparison of Figures 18 and 26.

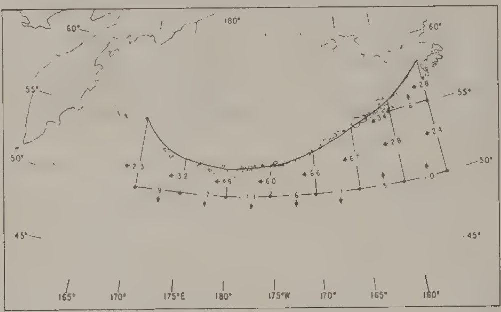

Figure 26. Integrated total transport (m³/sec × 10⁶) based on continuity, July 1959.

CONCLUSIONS

1. The Alaskan Stream is the extension of the Alaska Current which rather than recirculating in the Gulf of Alaska continues westward along the Aleutian Islands and provides a source of dilute surface water, and relatively warm water (4°C) at depths of 300 m, to the northwestern North Pacific Ocean.

2. The Alaskan Stream is continuous as far westward as long. 170°E where it divides sending one branch into the Bering Sea and one southwestward which joins the eastward flowing Subarctic Current at about long. 165°E (Fig. 27). The Komandorski Ridge may influence the surface flow in this area.

3. Observed surface velocities along the shelf near Atka and Adak Islands are as high as 100 cm/sec. Relative speeds at the edge of the shelf are in excess of 30 cm/sec and mean values across the Alaskan Stream are about 10 cm/sec, referred to 1,000-m level.

4. Relative transport referred to the 1,000-m level is approximately 6 × 10⁶ m³/sec. A southward component of Ekman transport in the eastern passes during the period considered contributed to the confinement of the Alaskan Stream southward of the island chain as far westward as long. 175°E.

5. Less than 25 percent of the observed relative transport in the Alaskan Stream can be derived from the local wind-driven transport. Wind-driven transport integrated across lat. 50°N between long. 155°W and the North American coast amounts to 5.2 × 10⁶ m³/sec, essentially balancing the observed transport in the Alaskan Stream.

6. The concurrence of the observed transport with the transport calculated from wind stress supports the theory that the Alaskan Stream is driven primarily by the action of the wind over a broad region of the north-

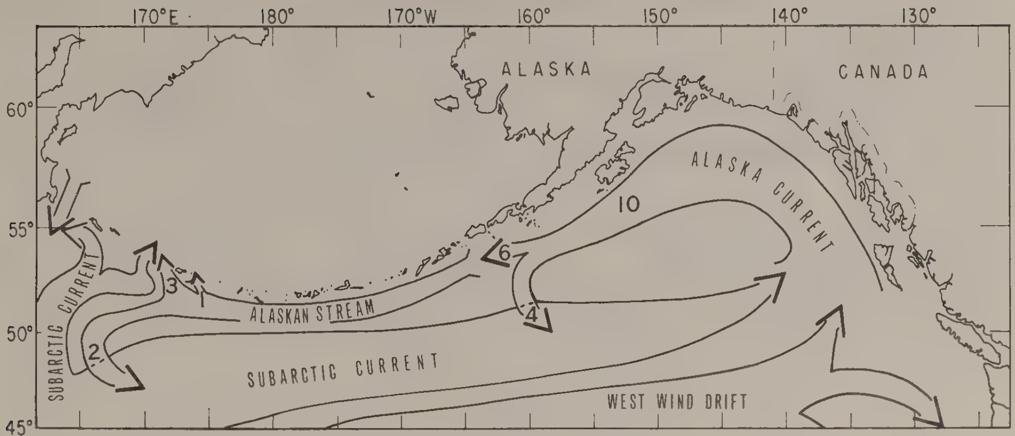

FIGURE 27. Schematic diagram of the Alaskan Stream. Numbers indicate volume transport ($m^3/sec \times 10^6$) referred to the 1000-m level.

east Pacific Ocean. The observed narrowness of the stream and continuity of transport also support the view that the Alaskan Stream is a western boundary current related to the general distribution of wind stress.

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A STUDY OF THE AFRICAN CICHLID, Tilapia heudeloti DUMERIL, IN TAMPA BAY, FLORIDA

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PRESENTED AT THE 18th ANNUAL MEETING

Southeastern Association of Game and Fish Commissioners

CLEARWATER, FLORIDA
October 18-21, 1964

(Reprinted from Proceedings of the Eighteenth Annual Conference, Southeastern Association of Game and Fish Commissioners, October 18-21, 1964.)

ABSTRACT

Ecological observations of the African cichlid, *Tilapia heudeloti*, are reported from the Tampa Bay estuarine system. Hydrological and biological data were compiled during 1963 and 1964. Specimens as large as 237 mm. (standard length) and weighing 487 grams were caught. Breeding appeared to begin in April or May and continue until December. Spawning occurred in brackish waters with an average salinity of 13.06%. In the study area, *T. heudeloti* was tolerant of water temperatures as low as 49.3°F. (9.6°C.) and as high as 89.6°F. (32°C.). Its food consisted of bottom detritus and phytoplankton. Attempts to catch tilapia in Tampa Bay with artificial or live bait were not successful. Economically, *T. heudeloti* offers some promise of becoming a commercially important estuarine species in Florida waters.

INTRODUCTION

In recent years, cichlid fish of the genus *Tilapia* have received attention as food, game, and bait fish in Africa, southeastern Asia, Hawaii, and the United States (Chimits, 1955, 1957; Uchida and King, 1962; and Swingle, 1960). The biology of some tilapias and their culture in ponds and rice paddies has been studied by many scientists. Fish (1955) and LeRoux (1956) worked on feeding habits, and Lowe (1955) on fecundity. Zaneveld (1959) and Brock (1954) reported on spawning of *Tilapia mossambica* in salt water and Baerends and Baerends-Van Roon (1950) recorded the social organization, care for offspring, and courtship of some other cichlid species. Aronson (1949) and Shaw and Aronson (1954) described the reproductive habits and oral incubation of *T. macrocephala*. Aronson (1949) stated that *T. heudeloti* may be a subspecies or variety of *T. macrocephala.*

The first record of the African mouth-breeder, *T. heudeloti*, in Hillsborough Bay, Florida was reported during the summer of 1959 between Mangrove Point and the Alafia River (Springer and Finucane, 1963). By 1962, the species became firmly established as a resident, and a small commercial fishery was developed.

Little was known of the life history and environmental requirements of *T. heudeloti* and its association with native species in the United States. This study was initiated in 1962 as part of the East Gulf Estuarine Program dealing with the ecology of estuarine biota in the Tampa Bay area.

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T. heudeloti was captured consistently at only two collecting sites (fig. 1). These locations were considered representative of the ecological habitats where *T. heudeloti* has become established. Station A is in a man-made channel connecting with Hillsborough Bay via Dug Creek. Station B is in Dug Creek, a stream receiving overflow drainage from fresh-water springs in an adjacent hatchery. The hydrology of both stations is influenced by tidal exchange throughout the year and by fresh-water inflow during the summer and fall. Water depth averaged 4 to 6 feet at Station A and 2 to 3 feet at Station B, although deep holes in both locations are 8 to 10 feet in depth. No attached bottom vegetation of any type was found at either location. Bottom composition at Station A consisted mainly of detritus and a fine sand-mud mixture. Station B had essentially the same bottom composition with a lower detrital content. Station A is surrounded by high grassy banks with some Australian *(Casuarina equisetifolia)* and longleaf pines *(Pinus palustris)*. The main emergent vegetation at Station B is the mangrove*(Rhizophora mangle)*.

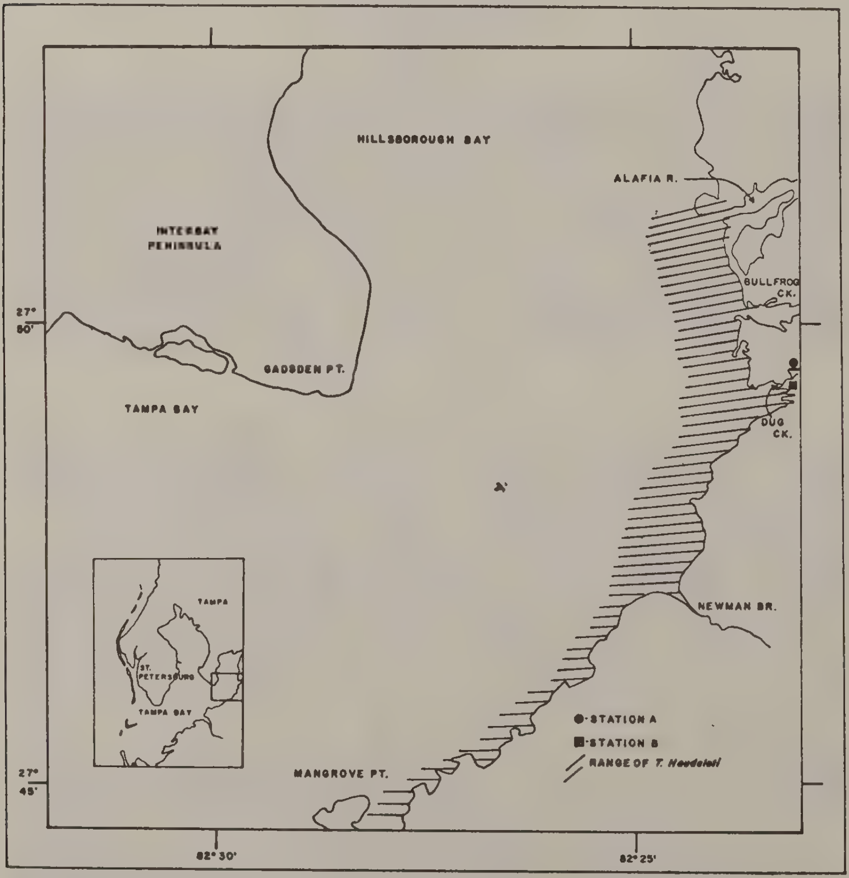
HILLSBOROUGH BAY
ALAFIA R.
INTERBAY PENINSULA
BULLFROG CK.
27° 50'
GADSDEN PT.
TAMPA BAY
DUG CK.
NEWMAN BR.
TAMPA
ST. PETERSBURG
TAMPA BAY
● STATION A
■ STATION B
RANGE OF T. Heudeloti
MANGROVE PT.
27° 45'
82° 30'
82° 25'

Figure 1.--Sampling stations and range of Tilapia heudeloti in the Tampa Bay estuarine system.

METHODS AND EQUIPMENT

Monthly seine hauls were made at each station with a 70-foot bag beach seine having ½-inch stretch mesh in the wings and ⅛-inch mesh in the bag. Tilapia retained for length-weight analyses were stored on ice and later frozen in polyethylene bags. The remainder of the specimens were preserved in 10 per cent formalin for later laboratory analysis.

Fish were measured to the nearest millimeter in standard length (SL) with a rule and Vernier calipers. Length-weight relationships were calculated according to the method of Lagler (1956). Selected specimens were weighed to the nearest tenth of a gram on a Mettler balance and checked for gonodal development and parasites. Age was determined from scales removed in an area between the dorsal fin and lateral line.

Small blue crabs *(Callinectes sapidus)*, caridean and penaeid shrimp, earth worms, artificial jigs, flies, and spoons were used as bait with fly and spinning rods to determine the catchability of the fish with sport gear.

Water samples were taken from the surface at each station to determine salinity, oxygen, and hydrogen concentration (pH). Water temperature was measured with a mercury thermometer to the nearest tenth of a degree centigrade. All salinity samples were collected in 120 ml. prescription bottles. The pH was determined from samples taken in 25 by 200 mm. pyrex glass culture tubes, fitted with polyethylene-lined screw caps. All oxygen samples were taken with modified Van Dorn bottles (Van Dorn, 1957) and treated immediately by the Windler method in 250 ml. glass-stoppered reagent bottles. Chlorophyll samples were collected in Erlenmeyer flasks and treated with magnesium carbonate to eliminate bacterial action. The complete methods used in chemical analyses have been described (Saloman, Finucane, and Kelly, 1964). Estimates of phytoplankton production were made according to the methods of Ryther and Yentsch (1957).

Sediment samples were taken with a manual coring device which extracted a core 2½ inches in diameter by 6 inches in length. Sand-size particles were separated by mechanical sieving, and silts and clays were determined by a soil hydrometer pipette method. An approximation of plant detritus was obtained by ignition (Moore and Gorsline, 1960). Per cent shell, sand, and detritus of each grain-size fraction was determined through particle counts on selected grids under low magnification by the method of Goodell[1].

RESULTS

Hydrology and Bottom Sediments

During 1963, monthly hydrographic parameters were measured at each sampling site (fig. 2). Water temperature was similar at both locations, averaging 23.3°C. at Station A and 24.3°C. at Station B. The lowest temperature occurred during February (14.3°C.) at Station A and the highest during September (32° C.) at Station B.

Salinity at both locations ranged from fresh to brackish. At Station A the lowest salinity occurred in December (1.62‰) and the highest during November (20.01‰).

The pH concentrations were essentially alkaline at both stations, ranging between 6.90 in June and 8.23 in September. The average at A was 7.60, and at B, 7.47. With the exception of January and February, the pH values at Station A were higher than at Station B.

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[1] H. G. Goodell (personal communication), Florida State University, Tallahassee, Florida.

Oxygen values at both locations ranged from 1.70 in June to 6.47 ml./1. in January. The averages were 4.12 ml./1. at Station A and 4.44 ml./1. at Station B. The percentage oxygen saturation ranged from 34.4 per cent in June to 131.3 per cent in September.

Chlorophyll measurements at both stations gave productivity values of 0.65 and 0.35 g C/m^2/day at Station A and 0.36 and 0.16 g C/m^2/day at Station B in July and August 1964. Chlorophyll a for these same periods was 12.29 and 22.4 mg/m^3 at Station A and 4.52 and 10.01 mg/m^3 at Station B.

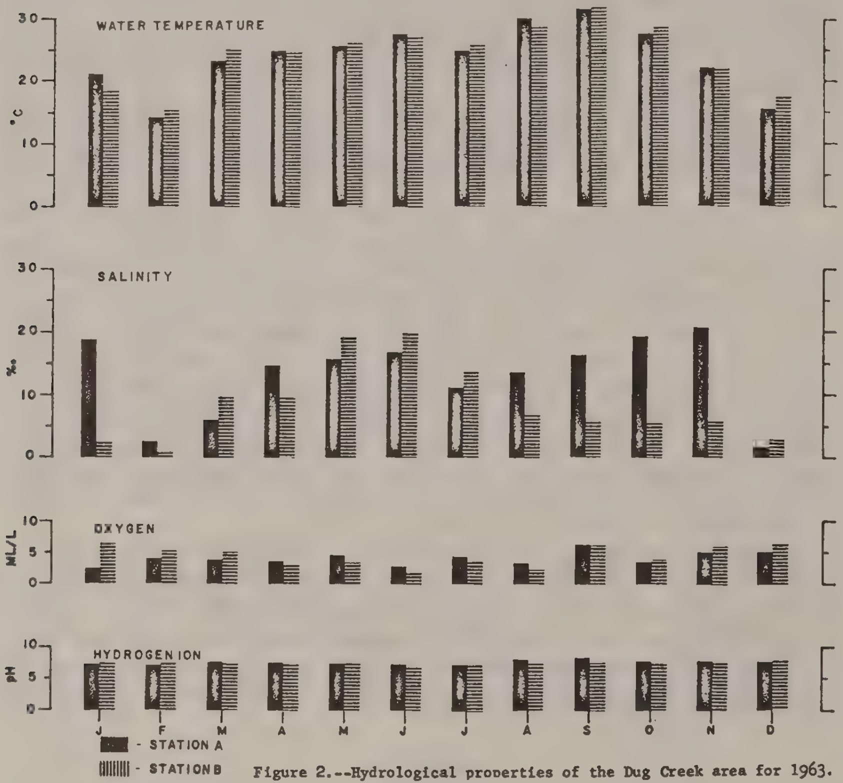

Figure 2.--Hydrological properties of the Dug Creek area for 1963.

Bottom sediment from Station A consisted of 67.36 per cent sand, 31.98 per cent detritus, and 0.67 per cent shell. Station B had 87.91 per cent sand, 11.97 per cent detritus, and 0.11 per cent shell. Clay and silt at both stations were negligible.

Natural History of Tilapia

Length-frequency data for 364 tilapias were determined for the period December 1962 to January 1964 (Table 1). The size range was 28 to 237 mm. (standard length). Examination of length-frequency and scale data revealed that the tilapia population consisted solely of fish in age groups O and I.

Representative length-weight relationships were plotted for 177 tilapias from the Dug Creek area (Fig. 3). Weight ranged from 5.1 grams for a fish of 46.7 mm. (SL) to 497.1 grams for one 220 mm. (SL). Most of the larger mature fish weighed more than 250 grams and were caught during January and March 1963. This indicates that weight increases rapidly in relation to length after length exceeds

100 mm. (SL). The logarithmic formula for the expression of this relationship is log W = log a + n log L, where W is the weight in grams, and L is the length in millimeters. The values for log a and n were found to be —3.848 and 2.772 respectively.

Ovary development and length-frequency data indicate that spawning starts in the spring and extends through the summer and fall. Mature ovaries were found in fish collected during March. Nest sites were also seen along the banks of Station A during the spring and summer. No nest sites or other evidence of spawning was noticed at Station B.

Stomach analyses showed that *T. heudeloti* is primarily a detritus and phytoplankton feeder. Contents of the intestional tracts (in descending order of magnitude) consisted of detritus, sand, diatoms, armored dinoflagellates, filamentous algae, and insects. The predominant phytop-

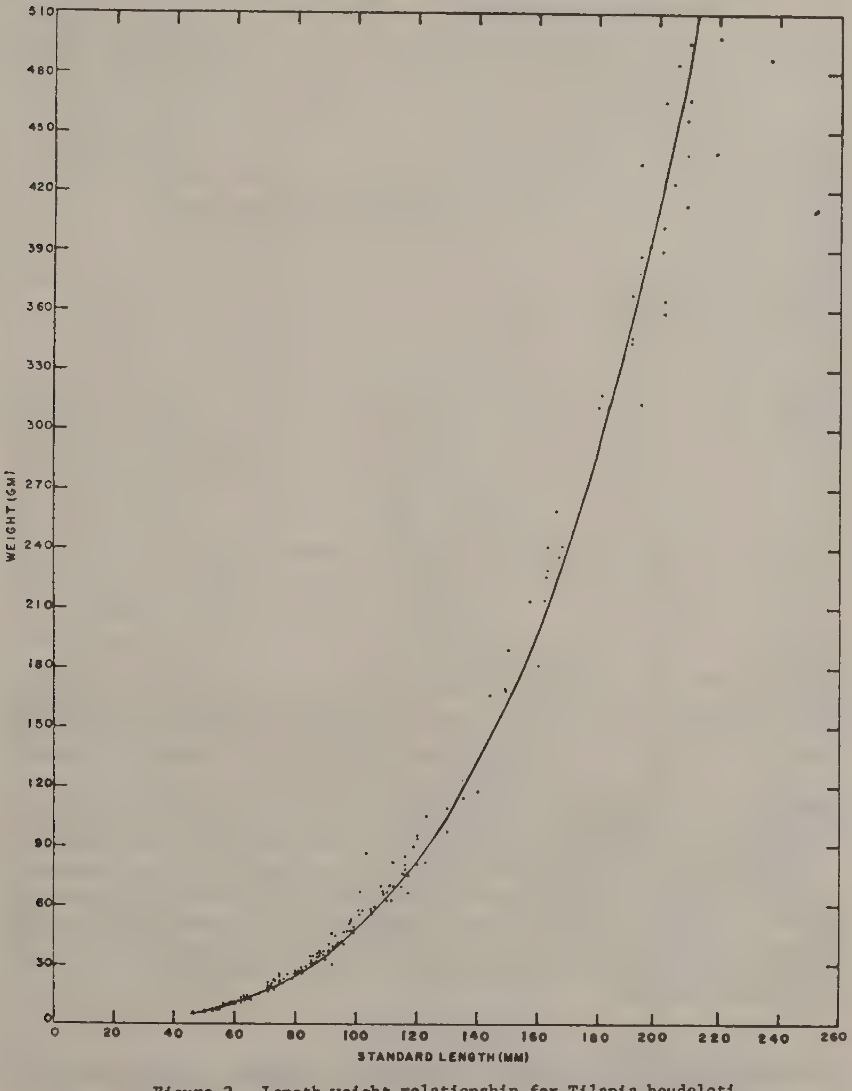

Figure 3.--Length-weight relationship for Tilapia heudeloti.

Table 1.--Length-frequency distribution of *Tilapia heudeloti* measured from the Dug Creek area

Mid-class	1962	1963												1964	
(mm.)	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Mar
20															
25															
30									11				1		
35									11			1	1		
40	1								3		1		2		
45			2							1			7	1	
50	2	1	4	1									5	3	
55	2		7	1								1	3	4	
60	2		5	1							1		2	3	
65	3		5	1							1	1	4	11	
70	2	1	4									1	2	8	
75		3	4										1	12	
80	1	3	3	1								1	5	16	
85		4	4										1	8	
90	1	5	7											6	
95	1	5	3									1	2	7	
100		4	3	1								1		7	
105		3			2							5		5	
110		7				2						3		2	
115	1	2			1	6							1	1	
120						4									
125		1				1						1			
130						2									
135		1													
140		1													
145															1
150						2							1		
155													1	1	
160														1	
165		2	1			2									
170		1								1				1	
175	1														
180	2	2													
185															
190	1												1	1	2
195	2	2		1										1	
200				1									1	1	3
205	2													2	
210													1	3	1
215												1			
220													1		2
225										1			1		
230	1													1	
235	1			1											
240															
Monthly total	26	48	52	9	3	19	0	0	25	3	3	17	44	106	9
Size range	40-235	48-197	46-163	50-237	103-116	110-167	-	-	28-42	47-225	42-64	36-215	32-223	46-230	144-220

lankton were diatoms and dinoflagellates (table 2). No evidence of fish-remains, crustaceans, or mollusks was noted. In nature, the species is essentially a herbivore, although in the laboratory it is omnivorous.

Twenty-eight species of fish appeared in catches with *T. heudeloti* (table 3). The dominant species were as follows: *Anchoa mitchilli*, *Menidia beryllina*, *Eucinostomus argenteus*, *Mollienesia latipinna*, and *Diapterus plumieri*. The majority of these fish were young-of-year and used the areas sampled as nursery grounds. No evidence of predation by tilapia was noted.

DISCUSSION

The ability of *T. heudeloti* to survive in waters of abnormally low temperature has been shown by Springer and Finucane (1963) when a

Table 2. Diatoms, dinoflagellates, and algae utilized as food by *Tilapia heudeloti.*

Genus	Species	Genus	Species
Achnanthes	curvirostrum	Navicula	cryptocephala
Achnanthes	hauckiana	Navicula	hungarica
Amphora	ovalis	Nitzschia	palea
Bacillaria	paradoxa	Nitzschia	closterium
Bellerochea	malleus	Nitzschia	filiformis?
Caloneis	formosa?	Opephora	sp.
Cocconeis	sp.	Peridinium	sp.
Cyclotella	striata?	Pinnularia	sp.
Diploneis	ovalis?	Pleurosigma	sp.
Gonyalax	sp.	Skeletonema	costatum
Gyrosigma	spencerii?	Stauroneis	sp.
Melosira	nummuloides	Synedra	ulna

Table 3. Species of fish collected with *Tilapia heudeloti* during 1963 at both sampling stations.

Genus-species	Common Name	Number Collected	Per Cent Total Collections[1]
Eucinostomus argenteus	Spotfin mojarra	694	100.0
Diapterus plumieri	Striped mojarra	336	84.6
Mollienesia latipinna	Sailfin molly	560	76.9
Centropomus undecimalis	Snook	20	69.2
Menidia beryllina	Tidewater silverside	971	69.2
Fundulus grandis	Gulf killifish	74	61.5
Anchoa mitchilli	Bay anchovy	3529	53.8
Archosargus probatocephalus	Sheepshead	9	46.2
Floridichthys carpio	Goldspotted killifish	84	38.5
Eucinostomus gula	Silver jenny	20	30.8
Trinectes maculatus	Hogchoker	7	30.8
Cyprinodon variegatus	Sheepshead minnow	27	30.8
Fundulus similis	Longnose killifish	9	23.1
Mugil trichodon	Fantail mullet	63	23.1
Leiostomus xanthurus	Spot	3	23.1
Cynoscion nebulosus	Spotted seatrout	6	23.1
Oligoplites saurus	Leatherjacket	12	23.1
Lutjanus griseus	Gray snapper	3	15.4
Lagodon rhomboides	Pinfish	21	15.4
Cynoscion arenarius	Sand seatrout	2	15.4
Lucania parva	Rainwater killifish	21	15.4
Gambusia affinis	Mosquitofish	1	7.7
Dorosoma cepedianum	Gizzard shad	1	7.7
Sciaenops ocellata	Redfish	2	7.7
Adinia xenica	Diamond killifish	5	7.7
Fundulus confluentus	Marsh killifish	1	7.7
Strongylura timucu	Timucu	4	7.7
Harengula pensacolae	Scaled sardine	4	7.7

[1] Per cent of total collections was based on the number of times these species were taken in 13 seine collections with *T. heudeloti.*

water temperature of 9.6°C. (49.3°F.) was recorded in the Tampa Bay area for a short period in December 1962. Some mortality of larger tilapia did occur, but there was no evidence of a massive fish kill. Crittenden[2] reported that experimental stocks of *T. nilotica* in a Florida State Management Area of Hillsborough County were also exposed to a water temperature of 8.9°C. (48.°F.) during this same period with no apparent mortality. The Java tilapia, *T. mossambica*, is more sensitive to low temperature and has been reported by Kelly (1957) to die at about 48°F. The mortality was limited to fish less than 6 inches in length, although some larger fish to 11 inches tolerated 37°F. (2.8°C.) for a short time. Aronson[3] believed that *T. marcrocephala* would not survive temperatures much below 60°F. (15.6°C.)

Low water temperature in the Tampa Bay area appears to inhibit the spawning of *T. heudeloti* from December to February. During these months, no spawning behavior was observed, and no nests were seen along the banks at either station. Our observations indicate that a minimal water temperature of 25°C. must be reached before spawning begins. Aronson (personal communication) stated that his experiences with laboratory specimens of *T. macrocephala* indicated optional temperature for breeding to be between 80 and 90°F. (26.7 and 32.2°C.).

Our attempts to spawn *T. heudeloti* in aquaria were not successful when salinity was greater than 34‰. Aronson (personal communication), however, reported successful breeeding of *T. macrocephala* in a sea-water aquarium and collection of the species in natural habitats where the salinity was nearly that of sea water. Zaneveld (1959) spawned *T. mossambica* in aquaria with running sea water at 36.2‰. Additional spawning took place at this same salinity at intervals of 28 to 50 days. The number of young produced never exceeded 25. Brock (1954) reported that Java tilapia also spawned in running sea water having a salinity of about 34.85‰ and a pH of 7.95.

Aronson (1949) and Shaw and Aronson (1954) reported extensively on the reproductive behavior, oral incubation, and embryology of *T. macrocephala* in laboratory aquaria. They found that oval nests were built having an average diameter of 13.2 cm. and an average depth of 2.6 cm. Of 76 observed spawnings, the male alone picked up the eggs in his mouth 81.8 per cent of the time, usually within one minute (average time 1 minute, 3 seconds). Incubation by the male ranged from 6 to 22 days with a mean of 14 days. Eighty females with a mean weight of 7.2 grams deposited an average of 50 eggs. The unfertilized mature ova are asymmetrical (Breder, 1943). They range between 2.0 and 3.5 mm. in length and 1.5 and 2.5 mm. in width. There is considerable variability in egg size within the ovary, although Shaw and Aronson (1954) stated that within each hatch the size was uniform.

Mature ovaries of *T. heudeloti* were recorded during March. Spawning of this fish probably first occurs during the spring. Two male specimens examined by Springer and Finucane (1963) were carrying eggs in their oral cavities as early as April. In laboratory experiments, Aronson (1951) found that *T. heudeloti* exhibited two peaks of reproductive activity: a major peak in March coinciding with the vernal equinox and a lesser one in October roughly coinciding with the autumnal equinox. In the natural West African habitat of *T. heudeloti*, spawning reaches its peak during December and January and tapers off during February, March, and April (Aronson, personal communication).

The youngest juvenile occurring in our study were caught in August, 1963 and ranged from 28 to 38 mm. (SL). The exact age of these fish is unknown, although specimens of *T. nilotica* from a local hatchery in this same size range were approximately one month old. McBay (1962) also reported that young *T. nilotica* measuring 4 inches (100 mm.) were approximately 50 days old, while 7-inch (195 mm.) specimens were 90 days old. Scale analysis of the larger tilapia (to 200 mm.) showed that most were still in their first year or early part of the second year. Annual rings on the cycloid scales were not distinct. No fish greater than 237 mm. (SL) was caught, however, indicating that in Tampa Bay *T. heudeloti* seldom lives longer than two years.

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[2] Edward Crittenden (personal communication), Florida Game and Fresh Water Fish Commission, Leesburg, Florida.

[3] Lester R. Aronson (personal communication), American Museum of Natural History, New York, New York.

The food of both young and adult *T. heudeloti* consisted primarily of bottom detritus and phytoplankton (table 2). Most of the phytoplankton were diatoms and armoured dinoflagellates of the genera, *Peridinium* and *Goniaulax*. In laboratory aquaria, however, these tilapia readily consumed sailfish mollies *(Mollinesia latipinna)*, caridean and penaeid shrimp. Stomach analysis conducted on *T. nilotica* by McBay (1961) showed that they were primarily plankton feeders and all sizes utilized phytoplankton to a large extent. Fish less than one inch in length (25 mm.) ate some small crustaceans (ostracods) while 3-5 inch fish (75-125 mm.) utilized insects, primarily Tendepedidae and Ceratopogonidae. Uchida and King (1962) and McBay (1962) reported some cannibalism by the larger, faster-growing individuals (20 mm. or larger) of the Java and Nile tilapias on other smaller juveniles.

From the types of fish species found to be associated with *T heudeloti*, it appears that little direct competition for food exists. The dominant species (table 3), such as the Bay anchovy, *A. mitchilli*, and the tidewater silverside, *M. beryllina*, are primarily plankton feeders but are reported to eat zooplankton principally. For example, Darnell (1959) found that the anchovies generally consumed rotifers and calanoid, and cyclopoid copepods when young. When mature, the diet consisted of fish and small shrimp. Larval silversides lived on copepods. Those 40 to 54 mm. fed primarily on isopods and those 55 to 79 mm. on amphipods. The sailfish molly, *M. latipinna*, is a herbivore, and the mojarras, *E. argenteus* and *D. plumieri*, are listed by Springer and Woodburn (1960) as eating ostracods, copepods, polychaetes, pelecypods, and insect larvae. The diet of cyprinodontids is similar to that of the mojarras but is more varied. Few of the young-of-year fish appear to need large amounts of phytoplankton as a primary food source. On the other hand, *T. heudeloti* is dependent on an abundant supply of phytoplankton such as that produced at Station A. The chlorophyll a values at Station A are approximately 10 to 22 times greater than those reported by Ryther and Yentsch (1957) from 14 tropical Atlantic stations. The higher rate of chlorophyll a and phytoplankton production at Station A probably is partially responsible for the greater abundance of *T. heudeloti* there than at Station B. The greater detritus content at Station A also appears influential in the support of comparatively large tilapia populations.

The practicability of developing *T. heudeloti* as a sport species is questionable. Attempts to catch this species with artificial or live bait were not successful. Swingle (1960) and Crittenden (1965) stated that both *T. mossambica* and *T. nilotica* could be caught on worms, although the Nile tilapias were more difficult to catch.

The greatest potential for the West African tilapia lies in its development as a commercial species. It has been marketed in Tampa on a limited scale by gill net fishermen during the winter and spring (Springer and Finucane, 1963). It is difficult to catch during the breeding season, although cast netting is sometimes successful. Since 1957, its range appears to have been confined chiefly to an area extending from the Alafia River to Mangrove Point along the eastern shore of upper Tampa and Hillsborough Bays (fig. 1). Other similar habitat types appear to be suitable for the species in Old Tampa Bay and in parts of lower Tampa Bay. Over three years of extensive field sampling throughout the Bay area have shown no further extension of its range. Since it appears to be essentially a euryhaline species, any of the major drainage areas along the southwest coast of Florida would seem to offer a suitable environment.

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Reprinted from BULLETIN OF MARINE SCIENCE
Vol. 17, No. 2, June, 1967
pp. 338–347
Made in United States of America

GENERIC DIFFERENCES IN PRODISSOCONCHS OF GULF OF MEXICO OYSTERS

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GENERIC DIFFERENCES IN PRODISSOCONCHS OF GULF OF MEXICO OYSTERS[1]

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ABSTRACT

Prodissoconchs (larval shells) of *Crassostrea virginica* and *Ostrea* spp. are illustrated and described from pediveliger larvae and spat reared in the laboratory. Prodissoconchs of *O. frons* and *O. equestris* were indistinguishable from each other, but they differed markedly from those of *C. virginica.* Definitive prodissoconchs of *Ostrea* possessed broad, blunt, orthogyrous beaks in contrast to the hooked, acute, opisthogyrous beaks of *C. virginica.*

Ostrea was a minor component (about 1 per cent) of the total spatfall in Santa Rosa Sound, Florida, in the summer of 1962.

INTRODUCTION

Distinguishing commercial species of oysters is a problem in studies on spatfall in areas where noncommercial species also exist. The commercial oyster of the Atlantic seaboard and the Gulf of Mexico, *Crassostrea virginica* (Gmelin), is sympatric with three species of small *Ostrea* in the southern parts of its range. *O. equestris* Say is common on shells of *C. virginica* in areas of high salinity south of Cape Hatteras and in the Gulf of Mexico (Galtsoff & Merrill, 1962; Galtsoff, 1964). *O. frons* (L.) is reported from the Gulf of Mexico (Gunter, 1951; Abbott, 1954). *O. permollis*, a yellow-shelled oyster in the eastern Gulf of Mexico and off the coast of North Carolina (Forbes, 1964), is not involved in the problem, since it inhabits sponges.

Ostreids are notably variable and often difficult to identify specifically. Gunter (1950), Thomson (1954), Menzel (1955), Yonge (1960), and Galtsoff (1964) have set forth the differences between *Ostrea* and *Crassostrea.* Oviparity and presence of a promyal chamber in *Crassostrea* stand in particular contrast to the larviparous condition and absence of promyal chamber in *Ostrea.* The three species of *Ostrea* in the Gulf of Mexico possess denticles in the hinge area that are absent in *C. virginica.* The two genera are externally difficult to distinguish in small individuals despite their internal differences.

Ranson (1948, 1960, and discussed by Galtsoff, 1964) regarded the form of the definitive prodissoconch to be useful in distinguishing genera and species of ostreids. Ranson's (1960) figures of 34 species indicate fairly consistent generic differences which are most pronounced in the left valves. Left valves are somewhat heart-shaped in *Crassostrea* because the beaks are directed posteriorly (opisthogyrous). Left valves are tear-drop shaped, more symmetrical, and nearly orthogyrous in *Ostrea.* Beaks are relatively blunt in *Ostrea.* Ranson included *C. virginica* but none of the western Atlantic *Ostrea.*

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Menzel (1955) was the first to publish figures of prodissoconchs of oysters from the Gulf of Mexico. His *C. virginica* agrees with Ranson's and his *O. frons* possesses the blunt beak of an *Ostrea.* That Menzel's *O. equestris* looks like *C. virginica* illustrates the difficulty inherent in searching for specific or generic differences in spat of uncertain identification. The present study describes prodissoconchs of larvae reared from parents identified as *C. virginica, O. equestris*, and *O. frons*.

METHODS

Larvae of *C. virginica* were reared from artificially fertilized eggs from adults collected in Santa Rosa Sound, Santa Rosa County, Florida. About 100 *O. equestris* and *O. frons* were obtained from the outer side of St. Vincent's Bar in Apalachicola Bay, Franklin County, Florida, and several from Santa Rosa Sound. Straight-hinge larvae of *Ostrea* were obtained by placing about 40 oysters singly in 100- to 600-ml beakers of seawater. Under such conditions one or two *Ostrea* usually liberated a brood of larvae in 5 to 8 days.

The five *Ostrea* which provided larvae were identified as follows. Broods 1 and 3 came from purple-red to chestnut, deep-cupped, elongated, plicated oysters from Apalachicola, of a type regarded as *O. frons.* Brood 2 came from a similarly shaped black-and-white-streaked *O. frons* from Apalachicola. Brood 4 came from a deep-cupped, deeply plicated *O. frons* from Pensacola Bay. This oyster possessed characteristic hooks on the lower valve; the upper valve was purplish-black, and the lower was lavender. Brood 5 came from a gray, circular, flat *O. equestris* from an anchor snagged in Pensacola Bay.

Larvae were reared by the general method used by Davis & Guillard (1958) and Loosanoff & Davis (1963). About 60,000 to 100,000 larvae were placed in a polyethylene pail with 8 to 10 liters of filtered seawater. Sodium sulfamethazine (Sulmet, American Cyanamid Co.)[3] was added as a bacteriostatic agent at a final dilution of 1:10,000. *Dunaliella euchlora* Lerche and *Platymonas* sp. (Chlorophyta) were each added at a rate of 10,000 cells per milliliter. Larvae were allowed to grow 48 hours; after that, water was changed daily. Stainless steel screens were used to retain the larvae (initial average opening diameter 44 μ; after several days growth,

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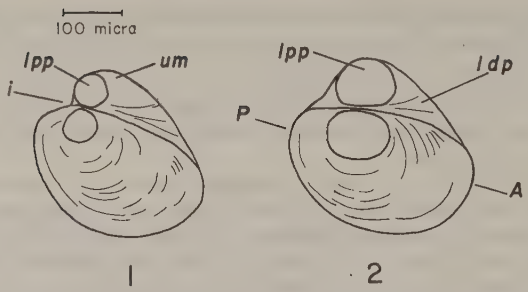
[3] Trade names mentioned in this paper do not imply endorsement of commercial products.



FIGURES 1, 2. Newly settled spat. 1, *Crassostrea virginica*, viewed from directly above; *i*, indentation; *lpp*, left primary prodissoconch valve; *um*, umbo of left definitive prodissoconch valve; 2, *Ostrea equestris* (brood 5) viewed from directly above; *PA*, longitudinal axis; *ldp*, left definitive prodissoconch valve; *lpp*, left primary prodissoconch valve.

88 μ). Cultures were maintained at about 24° C in an air-conditioned room, since mortality was excessive at normal summer temperatures of about 30° C.

Larvae of *C. virginica* began to set about 19 days after fertilization. Five broods of *Ostrea* larvae began to set 13 to 17 days after liberation. Spat were collected by placing substrates in culture vessels for 24 hours or more. Substrates were microscope slides and 50 mm × 75 mm pieces of cement-asbestos board or of Plexiglas (lightly sanded). Disarticulated prodissoconchs were prepared from eyed larvae cleaned in sodium hypochlorite solution (Clorox) diluted 1:1 and rinsed in distilled water. Valves were separated with a #00 insect pin and examined dry on a slide, with articulating surface downward.

CHARACTERISTICS OF *Ostrea* AND *Crassostrea* PRODISSOCONCHS

Straight-hinge Larvae.—*C. virginica* larvae attained the straight-hinge stage about 48 hours after fertilization (average length 69 μ ± 3.5 μ). *Ostrea* larvae were liberated from the mantle cavity of the parent in the straight-hinge stage (mean length of five brood means 117 μ ± 13.9 μ). Generic differences in length may reflect the larviparous habit of *Ostrea* and oviparous condition of *Crassostrea.* The shell of the straight-hinge stage, the primary prodissoconch, persists as a homogeneous cap over the beak of each valve of the definitive prodissoconch (Figs. 1 and 2).

Definitive Prodissoconchs in Setting Position.—Newly settled spat of *O. frons* and *C. virginica* were examined with a stereoscopic microscope (75 ×) from directly above (normal to substrate). Sufficient *O. equestris* larvae were not available to obtain spat. The spat were attached to the

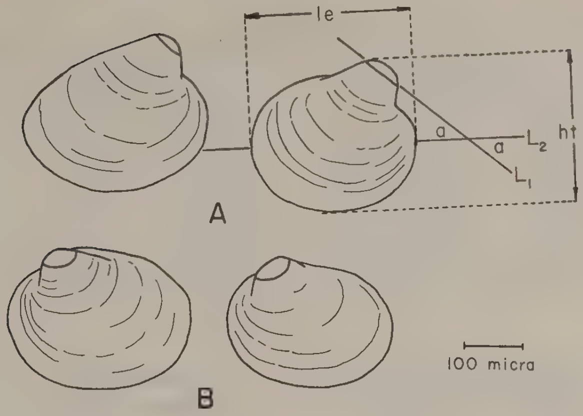


FIGURE 3. *Crassostrea virginica,* definitive prodissoconchs, disarticulated. A, left valves; B, right valves. L_1, longitudinal axis of primary prodissoconch; L_2, longitudinal axis of definitive prodissoconch; *a*, angle of rotation of longitudinal axis during larval development; *ht*, height; *le*, length.

substrate in a tilted position due to cementation at the ventral edge of the deeply cupped left valve. Generic differences in appearance of prodissoconchs resulted from opisthogyrous coiling in *Crassostrea* (as opposed to slight or no coiling in *Ostrea*) and the larger size of the primary prodissoconch of *Ostrea.* The following points of differences are apparent in spat examined on flat surfaces such as fouling plates (Figs. 1 and 2):

1. Beaks of *C. virginica* are hooked, acute, and directed posteriorly. Beaks of *Ostrea* are broad, blunt, and centrally located. *C. virginica* has an indentation behind the beak (Fig. 1).
2. The umbo of the left valve is clearly visible as a pronounced convexity anterior to the beak in *C. virginica.* This region varies from slightly convex to straight in *Ostrea.*
3. The primary prodissoconch is small and obscure in *C. virginica* but large and usually clearly visible in *Ostrea* at a magnification of 75 ×.

It was hoped that a size difference would aid in distinguishing the genera. To check this possibility, prodissoconchs were measured along the apparent longitudinal axis (Fig. 2) to minimize the possible effect of variation in tilt at setting. *O. frons* prodissoconchs averaged 340 $\mu \pm 13.8 \mu$ (N = 136); *C. virginica* averaged 317 $\mu \pm 16.1 \mu$ (N = 150). Broods 1 and 4 of *O. frons* used in this determination averaged 326 $\mu \pm 9.1 \mu$ (N = 50) and 346 $\mu \pm 10.0 \mu$ (N = 86), respectively. Broods 1 and 4 differed

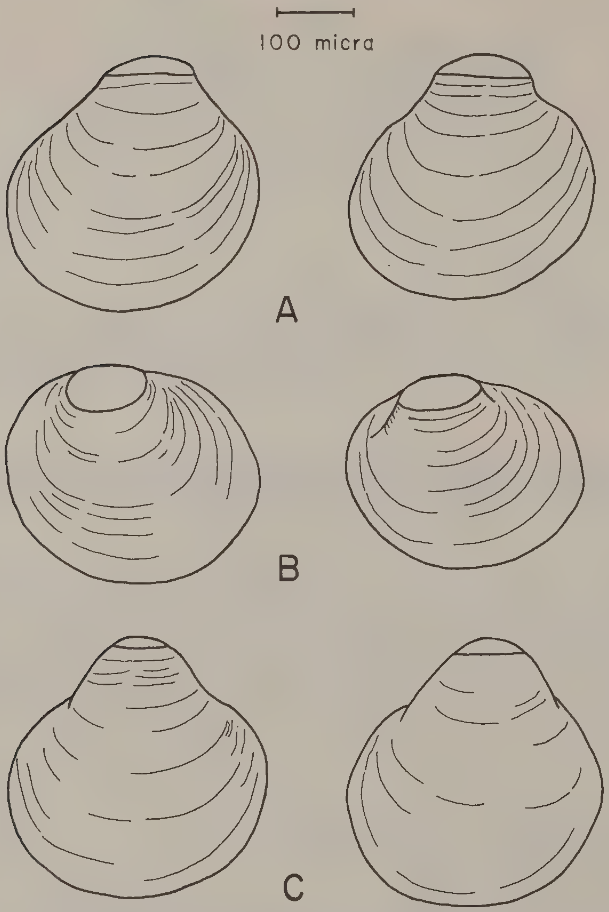


FIGURE 4. *Ostrea,* definitive prodissoconchs, disarticulated. A, left valves of *O. equestris* (brood 5); B, right valves of *O. equestris*; C, left valves of *O. frons* (brood 4).

significantly from each other and from *C. virginica* ($P < .001$ in a one-tailed *t*-test). Definitive prodissoconchs of *Ostrea* thus appeared to be slightly larger than those of *C. virginica*, but differences in shape are of greater practical value in distinguishing the genera in view of the considerable overlap in dimensions and unknown effects of environmental

TABLE 1

MEASUREMENTS OF LEFT VALVES OF DISARTICULATED PRODISSOCONCHS

Parentage[1]	Sample size	Mean length (μ)	Mean height/length ratio	Mean angle of coiling
C. virginica	50	301 ± 18.4	0.89 ± 0.031	33.6° ± 6.62°
O. frons 1	49	315 ± 10.0	0.97 ± 0.019	18.3° ± 5.19°
O. frons 2	50	332 ± 18.1	0.94 ± 0.033	17.9° ± 5.01°
O. frons 3	34	311 ± 15.6	0.96 ± 0.077	16.0° ± 3.89°
O. frons 4	48	332 ± 15.5	0.98 ± 0.026	18.9° ± 5.24°
O. equestris 5	48	311 ± 13.6	0.97 ± 0.021	20.3° ± 5.66°
All *Ostrea*	229	320 ± 19.1	0.96 ± 0.029	18.3° ± 5.23°

[1] Numbers that follow species names identify lots described in text.

conditions on prodissoconch size. *In situ* measurements given above are not comparable with measurements on disarticulated prodissoconchs (see next section).

Disarticulated Prodissoconchs.—Left valves isolated and laid flat revealed generic differences more clearly than did whole prodissoconchs in setting position (Figs. 3 and 4). All *Ostrea* valves possessed an indentation anterior to the beak; this area in *C. virginica* was straight to convex due to its opisthogyrous coiling. The beak of *Ostrea* was broad and blunt, whereas the beak of *C. virginica* was acute and hooked. Right valves reflected to a minor degree the characteristics of the left valves.

An attempt was made to identify metric differences between the two genera (Table 1). Length, measured approximately along the longitudinal axis of the pediveliger, was the greatest dimension of the shell exclusive of the umbo (Fig. 3). Height was arbitrarily taken as the greatest shell dimension at right angles to the longitudinal axis. Measurements were made with the aid of a Whipple ocular grid. A measure was sought for coiling. Opisthogyrous coiling results from rotation of the longitudinal axis during larval growth (Fig. 3, L_1, L_2). The angle *a* between the longitudinal axis of the primary prodissoconch and the longitudinal axis of the definitive prodissoconch was measured by aligning a Whipple ocular grid against a protractor through a camera lucida.

Prodissoconchs of *Ostrea* were larger than those of *C. virginica* (lengths 320 μ ± 19.1 μ and 301 μ ± 18.4 μ). Left valves of *Ostrea* had a greater height/length ratio (0.96 ± 0.029) than left valves of *C. virginica* (0.89 ± 0.031; $P < .001$ in a one-sided *t*-test). Left valves were less opisthogyrous in *Ostrea* than in *C. virginica* (rotation of longitudinal axis 18.3° ± 5.23° and 33.6° ± 6.62°; $P < .001$). Within *Ostrea*, interbrood and interspecific differences in height/length ratio and rotation of longitudinal axis were not significant, but interbrood differences in length were highly

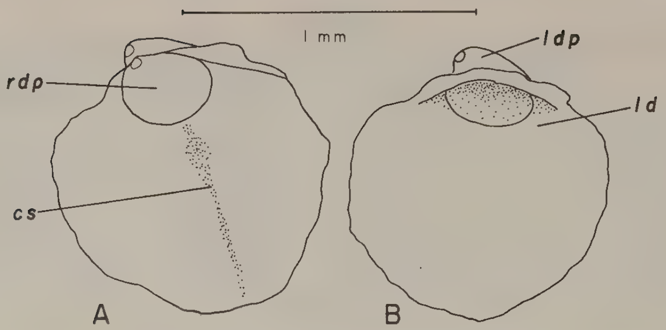


FIGURE 5. Spat of *Crassostrea virginica*. A, entire spat; B, with right valve removed; *cs*, chalky streak on right dissoconch valve; *ld*, left dissoconch valve; *ldp*, left definitive prodissoconch valve; *rdp*, right definitive prodissoconch valve.

significant ($P < .001$). Consistent differences did not exist between *O. frons* and *O. equestris*.

Lengths of prodissoconchs of *C. virginica* reported above agree remarkably with the range of 275 μ to 315 μ given by Loosanoff & Davis (1963). Lengths of *O. equestris* and *O. frons* exceeded the usual size of *O. edulis* L., which varies from about 280 μ to 300 μ and rarely attains 350 μ

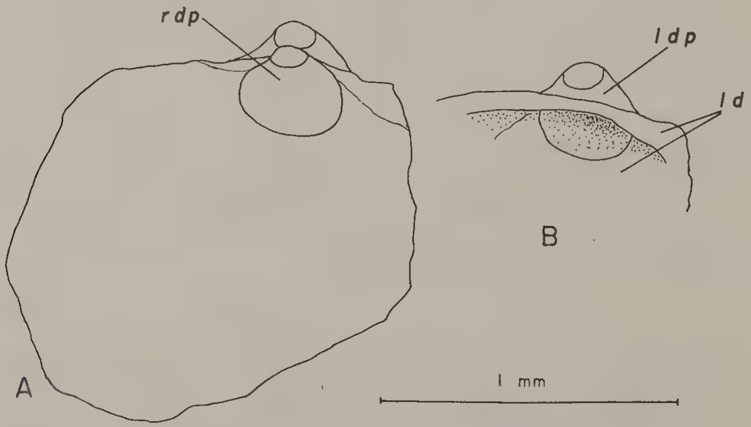


FIGURE 6. Spat of *Ostrea frons* (brood 4). A, entire spat; B, with right valve removed. Symbols as given in Figure 5.

TABLE 2

INCIDENCE OF *Ostrea* SPAT ON STANDARD 7-DAY FOULING PLATES, 1962

Date	Number of spat examined	*Ostrea* (%)	Number of spat per sq cm[1]	Number of *Ostrea* per sq cm[2]
May 5	200	0.5	15.5	0.08
June 4	742	0.1	4.3	[3]0.00
June 11	1,321	0.2	9.2	0.02
June 18	200	0.0	4.5	–
June 25	79	3.8	0.85	0.03
July 2	200	0.0	9.7	–
July 9	161	0.0	9.7	–
July 16	101	0.0	0.60	–
July 23	200	1.0	0.77	0.01
July 30	200	1.0	4.30	0.04
Aug. 6	187	1.6	1.97	0.03
Aug. 14	191	2.6	1.70	0.04
Aug. 20	200	1.0	37.5	0.38

[1] Butler's unpublished data. Spatfall on upper surface.
[2] Calculated as product of total spat density and percentage of *Ostrea*, rounded to the nearest significant figure.
[3] Less than 0.005.

(Korringa, 1941; Loosanoff & Davis, 1963). Loosanoff & Davis regarded size differences among *C. virginica, O. edulis*, and *O. lurida* Carpenter as not significant. Height/length ratios presented above cannot be compared with ratios of about 1.03 indicated by Loosanoff & Davis for *C. virginica,* since they defined the longitudinal axis as parallel to the hinge line.

Definitive prodissoconchs of *C. virginica* larvae reared in the laboratory resembled those illustrated by Menzel (1955) and Ranson (1960, Figs. 29-32). *Ostrea* prodissoconchs in the present study resembled those of *O. permollis* (Forbes, 1966), *O. denselamellosa* Lischke, and *O. stentina* Payraudeau (Ranson, 1960, Figs. 81-84, 89-92).

Dissoconchs of C. virginica and Ostrea frons.—Spat were allowed to grow to a length of 1 to 3.5 mm in culture vessels (Figs. 5 and 6). All *C. virginica* spat (110 specimens) had a chalky streak in the right dissoconch valve from the beak toward the distal margin. The streak was white by reflected light and later was paralleled by a black streak. A chalky streak was lacking in all *Ostrea frons* (Brood 4, 80 specimens) although the right valve became opaque. These observations agree in all respects with those of Menzel (1955) who first noted the chalky streak of *C. virginica* and its absence in *O. equestris.*

Characteristics of the left prodissoconch valve remained visible in spat with dissoconchs, especially when the right valve was removed (Figs. 5 and 6). Denticles (characteristic of dissoconchs of *O. frons, O. equestris,* and *O. permollis*) were not yet developed in *O. frons* 2 mm long. Denticles are absent in *C. virginica* dissoconchs of any size.

RELATIVE ABUNDANCE OF *Ostrea* AND *Crassostrea* SPAT IN SANTA ROSA SOUND

Standard fouling plates (4 inch × 4 inch cement-asbestos board), which had been used in a long-term study of spatfall in Santa Rosa Sound (Butler, 1965) were examined to determine the relative importance of *Ostrea* in the total spatfall.

Counts of spat identified on fouling plates exposed for weekly intervals from May 5 through August 20, 1962, are shown in Table 2. I dissected prodissoconchs for comparison with Figures 1 to 4 whenever necessary for certain identification. The highest percentage of *Ostrea* spat (3.8 per cent) occurred during a week of low total spatfall (0.85 spat/cm^2). The seasonal average of weekly percentages of *Ostrea* spat was 0.9 per cent. Absolute densities of *Ostrea* calculated from percentages indicate a hundredfold variation in set, even excluding periods during which no *Ostrea* were found. Although numbers of *Ostrea* spat were too low for statistical analysis, the data in Table 2 indicate considerable independence of *Ostrea* and *Crassostrea* setting. Although *Ostrea* appeared to be unimportant in Santa Rosa Sound in 1962, setting frequency of *Ostrea* has occasionally been as great as 50 per cent during periods of high salinity (Butler, personal communication). Menzel (1955) found a relatively higher percentage of *Ostrea* setting at high salinities.

ACKNOWLEDGMENTS

Dr. Philip Butler, Laboratory Director, suggested the problem, criticized the work, and provided facilities; Mr. James Keltner gave technical assistance; and Dr. Nelson Cooley offered suggestions and aid.

SUMARIO

DIFERENCIAS GENÉRICAS EN PRODISOCONCHAS DE OSTRAS DEL GOLFO DE MÉXICO

Las prodisoconchas de larvas y post-larvas de ostras, criadas en el laboratorio, fueron estudiadas por conocer características útiles para distinguir *Crassostrea virginica* de *Ostrea frons* y *O. equestris*. Estas especies coexisten en el Golfo de México. Las prodisoconchas de *C. virginica* tuvieron picos agudos fuertemente curvados (opistogiros). Las prodisoconchas de *Ostrea* spp. tienen picos romos, ortogiros. Las prodisoconchas persisten como gorros conspicuos en el pico de las prodisoconchas definitivas en *Ostrea* pero son obscuras en *Crassostrea*. Las diferencias son

mostradas en dibujos esquemáticos de valvas desarticuladas y post-larvas completas. Las prodisoconchas de *O. frons* y *O. equestris* no pudieron ser distinguidas en este estudio.

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Occurrence of *Sphyrion lumpi* on Silver Hake, *Merluccius bilinearis*

In July 1965, two silver hake, *Merluccius bilinearis*, were brought to the Biological Laboratory, Bureau of Commercial Fisheries, Woods Hole, Massachusetts, each with a parasitic copepod attached to the dorsal muscle between the dorsal fin and lateral line. The copepods were identified as female *Sphyrion lumpi* by Dr H. W. Stunkard. This is the first record of *Sphyrion* infestation of *Merluccius*.

The parasitized silver hake were part of a commercial catch made by a Gloucester dragger fishing in 16–18 fathoms of water around Lumbo Buoy (43°42′ N lat, 69°54′ W long) near Portland, Maine. Length and sex were not available because the fish had been headed and gutted. The estimated total length of each fish is 28 cm.

S. lumpi was first described from the lumpfish, *Cyclopterus lumpus*, by Kroyer (1845) and since that time has been known primarily as a parasite of redfish, *Sebastes marinus*, on both sides of the North Atlantic. Little is known of the early life history of this species and there is no evidence that a secondary host is involved. The incidence of *S. lumpi* on redfish was reviewed by Williams (1963). His paper includes a comprehensive bibliography on other marine fishes infected by *S. lumpi*, which include: wolffish, *Anarrhichas lupus*; salted hake (species unknown); *Nematonurus goodei* (=*N. armatus*); blue hake, *Haloporphyrus viola* (=*Antimora rostrata*); *Antimora australis*; *Cottunculoides inermis*; and *Macrourus sp.* All of these are deep-water species.

It is unlikely that the silver hake were infected in the area where they were caught. Kelly and Barker (1965), who reviewed the incidence of *S. lumpi* in the Gulf of Maine, reported that the copepod infestation on Gulf of Maine redfish increases during the winter and spring and increases with depth from 65 to 100 fathoms, where redfish are most abundant. Silver hake move seasonally from deep water (>60 fathoms) in the winter to shoal water (<60 fathoms) in the summer. Infection probably took place when the silver hake were in deep water with the redfish.

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Reprinted from International Commission for the Northwest Atlantic Fisheries,
Res. Bull. No. 3, p. 111

From Proceedings of the Forty-Seventh Annual Conference of Western Association of State Game and Fish Commissioners, Honolulu, Hawaii, July 16-20, 1967.

REVIEW OF SUBPOPULATION STUDIES ON SKIPJACK TUNA

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Skipjack tuna (Katsuwonus pelamis), because of their wide geographical distribution (Bureau of Commercial Fisheries, 1963) and the possibility of a significant increase in catch (Silliman, 1966; Rothschild, 1966), have drawn increasing attention from industrialists and scientists concerned with tuna fisheries in the United States and Japan (Marr and Tester, 1966; Indo-Pacific Fisheries Council, in press).

The necessity and methodology of identification of genetically self-sustaining populations ("subpopulations") of exploited fish were discussed and the merit of genetic methods among several existing methods was stressed by Marr (1957). Marr and Sprague (1963) discussed the usefulness of blood group characteristics in identification of subpopulations.

The present paper briefly reviews the evidence obtained by tagging, morphometric, and genetic studies and its interpretation to identify and delineate the subpopulations of skipjack tuna in the Pacific Ocean. The hypotheses proposed by Schaefer (1963), Rothschild (1965), and Kawasaki (1964) are also discussed.

EVIDENCE FOR IDENTIFICATION OF SUBPOPULATIONS

Tagging

In Hawaiian waters some 14,900 skipjack tuna tagged with California type-G and dart tags were released in 1954-58; 1,467 fish were recovered, all from the Hawaiian fishery (Yamashita and Waldron, 1958; Brock and Staff, 1959; Rothschild, 1966; Rothschild, in press). No further extensive skipjack tagging has been done in the central Pacific.

In the eastern Pacific 90,881 skipjack tuna were tagged in 1953-66, of which 4,401 were recovered from the eastern Pacific (Blunt and Messersmith, 1960; Schaefer, Chatwin, and Broadhead, 1961; Inter-American Tropical Tuna Commission, 1961-67). Some of these recoveries indicated northward and southward movement. Four of the tagged tuna had been recovered from the central Pacific by 1967. These recoveries provided direct evidence that the migratory range of skipjack tuna of the eastern Pacific extends westward to the central Pacific near Hawaii (Schaefer, 1963).

No extensive tagging of skipjack tuna has been conducted in the western Pacific.[1/] No fish tagged in either the central or eastern Pacific Ocean have been recovered from the western Pacific, although a large commercial fishery for this species exists in Japan.

[1/] Tagging of skipjack tuna in Palau, Caroline Islands, has been started recently by the U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu.

Morphometrics

Hennemuth (1959) compared selected external morphometric characteristics (Marr and Schaefer, 1949) of fish taken from the central and the eastern Pacific. He concluded that there are semi-independent populations in both the eastern and central Pacific and doubted whether further investigation of racial structure of skipjack tuna in these regions by morphometry would be fruitful.

Genetics

Inherited erythrocyte antigens (blood groups) and serum proteins (serum groups) have been studied. Three blood group systems, C, B, and Y, and two serum group systems (esterase and transferrin components) have been discovered.

C Blood Group System

Cushing (1956) found two phenotypes on the basis of the presence or absence of an antigen with normal bovine serum; Sprague and Holloway (1962) named the blood group the C system. They tested 1,344 specimens from the northern and southern central Pacific. The C system was not useful in separating samples from Hawaii, the Marquesas, the Tuamotu, and the Society Islands.

B Blood Group System

Sprague and Holloway (1962) found six phenotypes, called the B system, by the use of three reagents, anti-E, anti-K_1, and anti-K_2, in the samples taken from the central Pacific. After testing 1,014 specimens taken from the central Pacific Ocean, they observed a significant difference in the geographical distribution of the three groups of K_1, K_2,[2] and "-". They interpreted the difference as evidence for the existence of at least three reproductively isolated populations of skipjack tuna in the waters of Hawaii, the Marquesas, and the Tuamotu-Society Islands.

Sprague stated that the two genetically separable subpopulations entered the Hawaiian commercial fishery in 1962. He postulated the existence of seven subpopulations of skipjack tuna in the northern and southern central Pacific and the western Pacific (Sprague, 1963: Fig. 13).

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[2] The anti-K_2 reagent could not be reproduced, and is therefore no longer available (L. M. Sprague, personal communication).

Y Blood Group System

Using seven reagents, Fujino and Kazama (MS[3]) classified 15 phenotypes which form a blood group system. The system, called Y, was proved to be independent of the B blood group system, sex, and size of fish. Application of the Hardy-Weinberg law (Rasmuson, 1961: p. 32) indicated that the Y system is determined by six codominant alleles. Eleven lots totaling 913 blood specimens taken from Hawaiian waters were tested for the Y system. Gene frequencies for two lots appeared to be different from those of the other nine. The heterogeneity test for the pooled data of the gene frequencies of 11 samples, however, failed to demonstrate that the heterogeneity is significant. Finally Fujino and Kazama stated that if the differences between the nine lots of samples and the two lots of samples are real, an extensive collection of population data is needed before the differences can be demonstrated.

Serum Esterase System

Using horizontal starch-gel electrophoresis, Fujino and Kang (in press) found six esterase bands in skipjack tuna serum specimens. Three clear bands, named 1, 2, and 3 in their descending order of mobility, occurred regularly. Three other faint bands occurred in very low frequencies and were not considered to be useful in population study. Six individual differences were observed as combinations of the three clear bands. Statistical tests made under the Hardy-Weinberg law indicated that the six phenotypes form a system (E_{SJ} system) determined by three alleles. The E_{SJ} system was independent of blood group systems B and Y, sex, and size of fish.

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[3] Fujino, K. and T. K. Kazama. MS. The Y system of skipjack tuna blood groups. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii 96812.

A total of 8,804 specimens taken from the Atlantic and Pacific Oceans was tested for the E_{SJ} system. Mean, standard deviation, and range of distribution of a gene (E_{SJ}^{1}) are shown in Table I for each geographical area sampled. On the basis of heterogeneity tests for the gene frequencies of these specimens (Table II), Fujino and Kang concluded that (a) no significant heterogeneity was observed within each geographical area, (b) a population in the equatorial Atlantic is different from any populations recognized in the Pacific, (c) eastern Pacific (Baja California) specimens were indistinguishable from those of Hawaiian waters, and (d) at least one population in the western Pacific (Japan and Palau) is different from the population in Hawaiian and eastern Pacific waters. They commented on the necessity of collecting more extensive population data, particularly from the eastern Pacific, Japanese, and Palauan waters, before the relationships of skipjack tuna resources of the eastern and central Pacific and those of Palauan and Japanese waters can be described.

Transferrin System

Barrett and Tsuyuki (in press) and Fujino and Kang (MS[4]) conducted independent studies of the transferrin system both by the use of starch-gel electrophoresis and by labeling with radioisotope Fe^{59}, followed by preparation of radioautographs. Barrett and Tsuyuki found three bands, named C, D, and E in their descending order of mobility, and recognized six individual differences, CC, CD, DD, DE, EE, and CE, which they interpreted to be determined by three alleles according to Hardy-Weinberg analysis. After testing 175 specimens taken from the north and equatorial eastern Pacific, they stated that there was neither a geographical cline from north to south nor a significant difference of gene frequencies within the area examined.

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[4] Fujino, K. and T. Kang. MS. Transferrin groups of tunas. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii 96812.

TABLE I

Frequency of the Gene E_{SJ}^{1} of Serum Esterase System of Skipjack Tuna in Different Areas[1]

Area	No. of Lots	No. of Fish Examined	Frequency of Gene		
			Range	Mean	Standard Deviation
Atlantic	2	117	0.761-0.800	0.780	0.020
E. Pacific	6	386	0.470-0.605	0.536	0.053
Hawaii	79	7,004	0.350-0.600	0.483	0.051
Japan	5	398	0.584-0.679	0.645	0.034
Palau[2]	13	899	0.643-0.770	0.697	0.043

[1] Cited from Fujino and Kang, in press.

[2] Includes more recent data tested for nine lots of samples totaling 603 fish.

TABLE II

Results of Heterogeneity Tests Summarized for Gene Frequencies of E_{SJ} System in Skipjack Tuna[1]

Area	χ^2	df	Probability
	Intra-areal		
Atlantic	0.2	1	$P > 0.5$
E. Pacific	2.7	5	$P > 0.7$
Hawaii	62.2	78	$P > 0.8$
Japan	2.3	4	$P > 0.5$
Palau	8.1	12	$P > 0.7$
	Inter-areal		
E. Pacific-Atlantic	27.8	7	$0.001 > P$[2]
E. Pacific-Hawaii	68.9	84	$P > 0.8$
Hawaii-Japan	116.1	83	$0.05 > P$[2]
Hawaii-Palau	218.3	91	$0.001 > P$[2]
Japan-Palau	14.1	17	$P > 0.5$

[1] Tested for E^1_{SJ} and combined E^2_{SJ} and E^3_{SJ}, which determine esterase bands 1, 2, and 3, respectively.

[2] Heterogeneity is significant.

Fujino and Kang (MS[4]) found five phenotypes, 1-2, 2, 2-3, 3, and 1-3 as combinations of three bands 1, 2, and 3. (A theoretically possible phenotype 1 was not observed.) The system was proved to be determined by three codominant alleles and independent of blood group systems B and Y, serum esterase system, and sex. Recent direct comparison, after an exchange of serum specimens between the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, and the Inter-American Tropical Tuna Commission, indicated that bands 1, 2, and 3 of Fujino and Kang correspond to the bands C, D, and E, respectively, of Barrett and Tsuyuki (I. Barrett, personal communication). Heterogeneity tests of gene frequencies for the 2,807 specimens examined by Fujino and Kang and 175 specimens (eastern Pacific only) examined by Barrett and Tsuyuki showed that there is no significant heterogeneity within and between areas for skipjack tuna from the equatorial Atlantic, eastern Pacific, Hawaii, Japan, and Palau.

Fujino and Kang further described in general the evidence of differential viability among phenotypes of transferrin and their association with the age of fish and discussed the mechanisms that maintain polymorphism. They then proved that the gene frequencies are maintained unchanged between and within generations and that the gene frequencies are still valid in general as genetic markers in subpopulation studies.

HYPOTHESES DELINEATING SUBPOPULATIONS

Schaefer's Hypothesis for the Eastern and Central Pacific

Schaefer (1963) stated that it appears that at least some fish of the west coast skipjack tuna population range far to the westward. He based his argument on these lines of evidence: (1) There are no significant morphometric differences among skipjack tuna from the eastern Pacific, Hawaii, and Marquesas, (2) there are no differences in blood type incidences between Hawaii and the eastern Pacific, (3) tagged fish have moved from Baja California to the central Pacific (Inter-American Tropical Tuna Commission, 1963), and (4) there is little evidence of skipjack tuna spawning in the eastern Pacific fishing region.[5/] Some problems in interpretation of the evidence on item (1), as well as part of the description of Schaefer's hypothesis, is discussed later.

[5/] According to E. H. Ahlstrom (personal communication addressed to W. Matsumoto), large collections of skipjack tuna larvae were made in 1967 in the eastern Pacific (7° S, 119° W).

Rothschild's Hypotheses for the Eastern and Central Pacific

Rothschild (1965) stated that (a) the skipjack tuna in the eastern Pacific come from the central Pacific, (b) skipjack tuna in the central Pacific are not a single homogeneous population unit, and (c) the skipjack tuna from the Marquesas zone do not enter the eastern Pacific fishery areas. The major items of evidence among the many from which his hypotheses were synthesized, are (1) larval distribution--larvae are abundant in Hawaiian waters and the equatorial central Pacific and scarce in the eastern Pacific[5/] (Matsumoto, 1958; Klawe, 1963); (2) long-distance movements of tagged fish from Baja California to the central Pacific (Inter-American Tropical Tuna Commission, 1963 and 1964); and (3) immunogenetic results, which indicated the existence of numbers of subpopulations in the Pacific (Sprague, 1963). Finally he suggested that an immunogenetic study be conducted to determine the relationship between the adult and juvenile populations, which would provide information on the loci of origin of each subpopulation.

Two items of evidence, (1) and (2), used by Rothschild are the same as those used by Schaefer, but the third is not. The difference of their views on item (3) of Rothschild's evidence led to a difference in their hypotheses on the relation of skipjack tuna between the Marquesas and the eastern Pacific, stated by Rothschild as item (c) but not by Schaefer, although other points are very similar, so far as subpopulation delineation is concerned. Item (3) of Rothschild's evidence is discussed later.

Kawasaki's Hypothesis for the North Pacific

Kawasaki (1964) stated that the skipjack tuna in the waters off northeastern Japan has an intimate interrelation with those in Hawaii and the eastern Pacific, and therefore hypothesized a transpacific population with a common element. In addition he stated that the skipjack tuna in the archipelagoes of the southwestern Pacific, including the Philippines, might form a local population or populations. He retained his earlier view (Kawasaki, 1955) on the existence of different groups in the waters adjacent to Japan by stating that there are five groups in the region that display life patterns different from each other--the Goto group and chain group in the East China Sea-Ryukyu area, the chain group in the Izu-Bonin Islands area, and the inshore group and offshore group off northeastern Japan.

The evidence he used was: (1) similar fluctuations in catches off Japan and Hawaii and in the eastern Pacific over 10 years, accompanied by similar changes in size distribution; (2) growth curves based on seasonal progression of modal length; (3) all evidence used by Schaefer (1963); and (4) spawning area and season--the major spawning of skipjack tuna in the Pacific occurring in a relatively restricted area centered at the Equator and extending west of 140° W., and the effective spawning season coming in midsummer of the Northern Hemisphere and being comparatively short.

It is obvious that the evidence on spawning area and season (4) did not include recent data on the extensive distribution of spawning in time and space (Matsumoto, 1966). Kawasaki accepted all evidence used by Schaefer (1963), but not the view of Sprague (1963) that very large fish (26 lbs.) taken in Hawaiian waters originated in the eastern Pacific, within the California Current system.

Some points in his description of the hypothesis are not clear to me; I do not know if "population" was used in the sense defined by Marr (1957) and do not fully understand the relationship of skipjack tuna from the Philippine area with those from the East China Sea (Goto group), although he discussed this relationship earlier (Kawasaki, 1955).

Some problems relating to interpretation of his evidence on items (1), (2), and (4) are discussed later.

SUMMARY OF RECENT INFORMATION

What Can Be Said From the Most Recent Information?

Although it is not intended to propose a model for population structure here, the following statements can be made on the basis of the evidence described in the earlier sections of this paper and that used by other authors.

a. The skipjack tuna taken by the Palauan fishery belong to a subpopulation which does not appear in the Hawaiian fishery.

b. The skipjack tuna taken in Japanese coastal waters are also different from those that appear in the Hawaiian fishery, but it is not yet clear whether the fish that appear in Japanese and Palauan waters belong to a single homogeneous subpopulation or to separate subpopulations.

c. The skipjack tuna that appear in the Hawaiian fishery do not constitute a homogeneous population unit. It has not, however, been clarified whether the fish can be clearly distinguished into more than one subpopulation as indicated by the earlier study (Sprague, 1963) or come from a single population in which a genetic cline exists.

d. It is not clear whether skipjack tuna that appear in the central and eastern Pacific are recruited from a common population or whether there is a population in one of the two areas which does not appear in the other area.

e. None of our recent data conflict with the hypotheses proposed by Schaefer (1963) and by Rothschild (1965) for the relations between skipjack tuna of the central and eastern Pacific.

The major piece of evidence used to reach these conclusions were inter- and intra-areal comparisons of gene frequencies of the serum esterase system (Tables I and II; Fujino and Kang, in press) and results of analyses of other genetic systems.

The above item (a) supports the earlier results of the B blood group system (Sprague, 1963). Item (b) rather conflicts with the model proposed by Kawasaki. Items (c) and (d) do not immediately conflict with the results of Sprague (1963) and the view of Rothschild (1965), but rather suggest the necessity of further study to clarify the problem. Item (d) is discussed later.

PROBLEMS AND POSSIBLE SOLUTIONS

Several problems arise in the interpretation of the data cited. The authors are not in total agreement, and the material from Hawaii, at least, is susceptible of varying interpretations in the following paragraphs, these problems will be mentioned and possible methods of solving them will be suggested.

Problems

There are obvious differences in opinion among different authors. These are: (1) the interpretation by Hennemuth (1959) that morphometric differences suggested the existence of semi-independent populations was not accepted by Schaefer (1963); (2) coincidence in spatiotemporal distribution of catch and the modal length used by Kawasaki (1964) for the delineating of subpopulations was not adopted by Rothschild (1965); and, (3) the results of B blood group study, which were interpreted by Sprague (1963) to indicate the existence of more than one subpopulation in the Hawaiian fishery, were not accepted by me.[6/]

[6/] The reason for this difference in interpretation is that recent data have suggested an association of the B blood group system with size of fish. This problem was not mentioned by Sprague.

Another fact which might be related to the problems of population structure in Hawaiian and eastern Pacific waters has not been mentioned earlier: Gene frequencies of both serum esterase system (Table I) and transferrin system (Fujino and Kang, MS[4]: Fig. 2) revealed the distribution range for samples taken from Hawaii as being much wider than that for samples taken from other areas. This phenomenon was observed even when as few specimens were analyzed as had been taken from a less extensively sampled area (e.g., Palau). This result suggested that possible existence of two or more populations whose genetic compositions closely resemble each other. This conclusion suggests the necessity of studying the distribution of gene frequencies of as many genetic systems as possible (that is, range, mean, standard deviation, and shape of distribution curve--symmetric or polymodal) by collecting extensive population data from the areas concerned to describe accurately the intra- and inter-areal relationships.

Possible Solutions

Possible aids to the solution of the various problems noted above can be briefly itemized as follows: (1) find as many genetic systems as possible; (2) select genetic systems with regard to amenability of Hardy-Weinberg principle, independency of sex and age, appropriate differential incidence of occurrence as indicator, and technical easiness to use in population studies; (3) use concurrently the multiple systems selected, and (4) tag fish to provide supplemental possible evidence when the genetic concept gives negative evidence--even though tagging studies of skipjack tuna suffer from such disadvantages as the short life history of the fish, the great size of the population, the requirement for a recovery mechanism (i.e., a fishery), and the heavy demands on budget and manpower to obtain useful information.

ACKNOWLEDGMENTS

I acknowledge with sincere thanks critical comments on the manuscript given by Mr. J. C. Marr and Dr. B. J. Rothschild.

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Ecological Significance of a Drifting Object to Pelagic Fishes

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Reprinted from PACIFIC SCIENCE, Vol. XXI, No. 4, October, 1967

Ecological Significance of a Drifting Object to Pelagic Fishes

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PELAGIC FISHES frequently gather around drifting material in the open sea. Commercial and sport fishermen regard the immediate vicinity of drifting material as a potentially good area for trolling. Commercial seine and pole-and-line fishermen in Japan, Indonesia, and Malta anchor floating material to attract fish. Fish have been reported gathered around floating algae, coconuts, and pumice (Besednov, 1960; Senta, 1965); floating logs (Inoue, Amano, and Iwasaki, 1963; Kimura, 1954; Yabe and Mori, 1950); coconut fronds and slabs of cork (Hardenberg, 1949; Soemarto, 1960; Galea, 1961); and rafts (Kojima, 1960; Heyerdahl, 1950; Evans, 1955). In addition to clustering near these inanimate objects, the young of many pelagic fishes gather beneath jellyfish (Mansueti, 1963); fish-jellyfish associations have much in common with the associations studied in the present paper.

Hypotheses suggested to explain the accumulation of fish around inanimate floating objects include: (1) fish seek shelter from predators (Soemarto, 1960; Suyehiro, 1952); (2) larger fish prey on the concentration of smaller fish (Kojima, 1956); (3) fish feed on algae or decaying coconut fronds (Reuter, 1938; Soemarto, 1960); (4) fish seek the shade under the object (Suyehiro, 1952); (5) fish use floating objects as a substrate on which to lay their eggs (Besednov, 1960); (6) the shadow of the object makes zooplankton more visible to the fish (Damant, 1921). At the beginning of the present study we suggested still another hypothesis: floating objects are cleaning stations, where pelagic fishes have their parasites removed by other fish. Such symbiotic cleaning associations are well documented for fishes in inshore waters (Eibl-Eibesfeldt, 1955; Limbaugh, 1955, 1961; Randall, 1958).

To test these hypotheses, studies were made from a raft with an observation chamber (Fig. 1) built at the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, and set adrift in the central Pacific (Gooding, 1965). The present paper describes and interprets the observations in light of the above hypotheses.

AREAS AND METHODS OF OBSERVATION

Observations were made in two areas, one off the leeward coast of the island of Hawaii and the other near the Equator in the central Pacific (Fig. 2).

Observations were made in Hawaii between September 28 and October 11, 1962, and between August 1 and August 26, 1965. This area offers two advantages: first, it is sheltered from the northeast trade winds and the sea is relatively calm; second, essentially pelagic conditions (water deeper than 800 m) occur within 1 mile of shore. During 345 hours of drift, 173 hours of daylight observations and 9 hours of night observations were recorded. Eleven drifts were made, the longest of which was 52 hours.

Two drifts were made between February 14 and March 20, 1964 in the storm-free belt at the convergence of the northeast and southeast trade winds near the Equator. On the first drift the raft was launched 9 nautical miles north of the Equator in an area of upwelling. During 194 hours of drift, 91 hours of daylight observations were made. The second equatorial drift began 153 nautical miles south of the Equator. During 215 hours of drift, 100 hours of daylight observations were made.

The raft drifted 585 nautical miles west during the first equatorial drift and 395 nautical miles west during the second. Most of the drift was due to surface currents. To reduce wind-induced drift a 28-foot parachute was used as a sea anchor during part of the first drift and all of the second. (It was also used during several of the Hawaiian drifts.)

While the raft was adrift, wave heights ranged from 0 to 1 m at Hawaii and from 1 to

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[1] Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii. Manuscript received August 19, 1966.

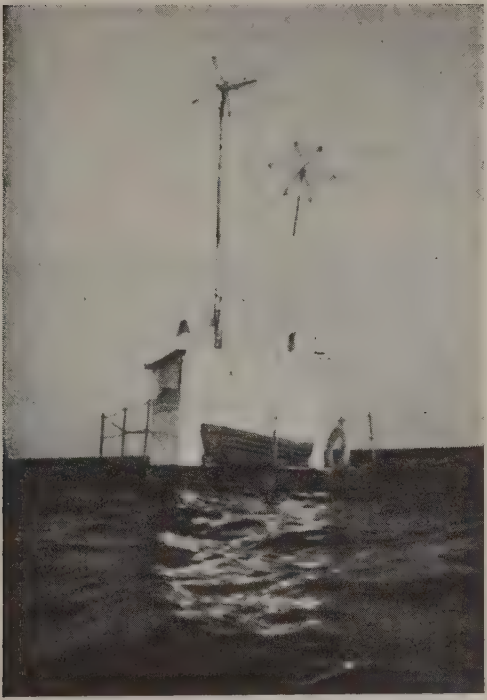

FIG. 1. The observation raft used in study.

2 m at the Equator. Average wind speeds ranged from 10 to 15 knots. Cloud cover seldom exceeded 30%.

The observation chamber beneath the raft (Fig. 3) accommodated a single observer, who could view the area beneath and around the raft. Two observers manned the drifting raft from dawn to dusk. Watch positions in the chamber were rotated each hour. Nights were spent on the ship, which remained 1–3 miles from the raft. A skiff provided transportation between ship and raft.

The observers noted the number of each kind of fish at the raft, their position under or near the raft, and their reaction to the raft and to other fish or invertebrates. Night observations were made under bright moonlight, but a flashlight was used at intervals to determine more accurately the positions of the fish. The accumulation was quantified by making population counts of the species present at intervals during the day. An estimate of population changes during the night was obtained by comparing the last count in the evening with the first count on the following morning.

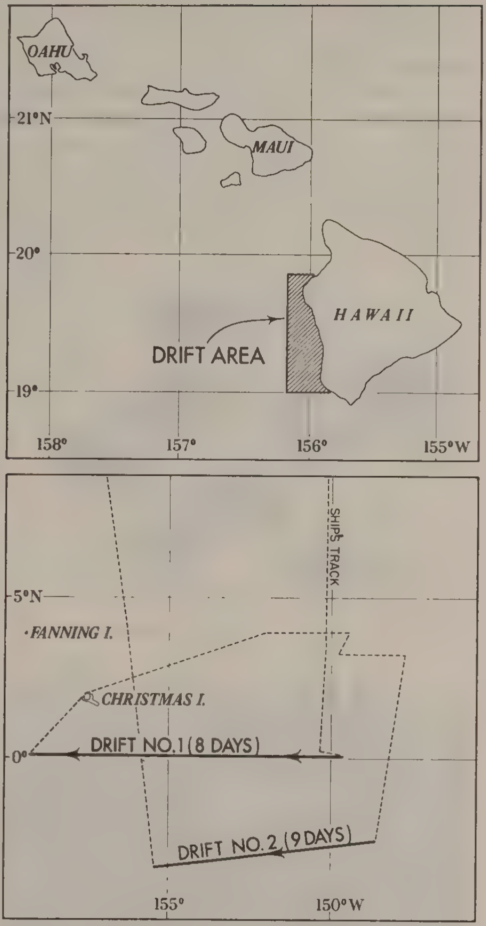

FIG. 2. Areas in which drifts were made with the observation raft, off Hawaii (*upper panel*) and near the Equator (*lower panel*).

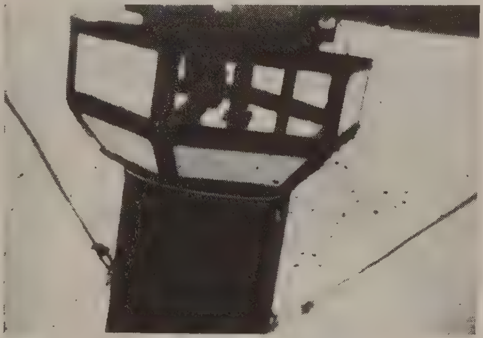

FIG. 3. The observation chamber of the raft. Dark specks to right of chamber are small fish. The white object behind the chamber is the parachute drogue.

In addition to direct observations, 6,200 ft of 16-mm color movies, and numerous still pictures were taken.

Fish were captured at the raft with dip nets, baited hooks on hand lines, casting and trolling lures, and a small purse seine net attached to the sides of the raft. To avoid interference with the accumulation of animals, collections were made only at the end of the drifts. Stomach contents and external parasites of fish captured at the raft were preserved.

FISHES AT THE RAFT

Animals seen from the observation chamber (some are shown, as photographed from the chamber, in Figures 4*a*–*f*) were broadly

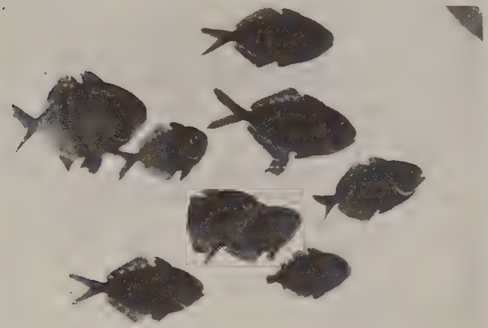
FIG. 4*a*. Freckled driftfish.

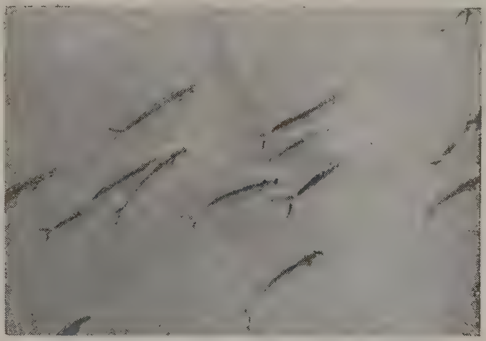
FIG. 4*d*. Juvenile dolphin.

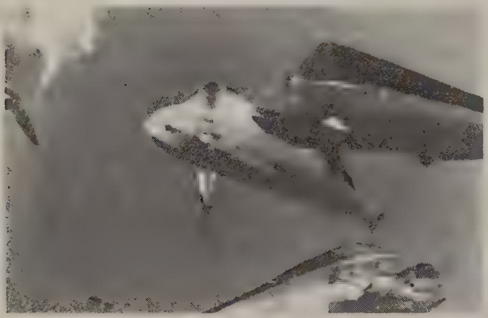
FIG. 4*b*. Adult dolphin.

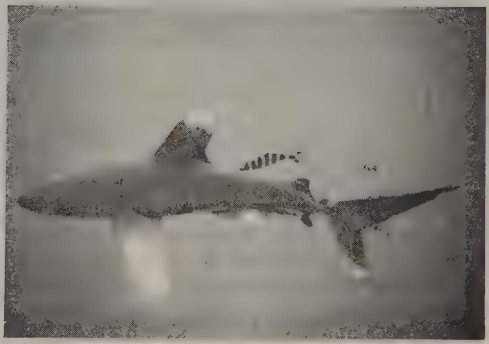
FIG. 4*e*. Whitetip shark accompanied by pilotfish and remora.

FIG. 4*c*. Amberjack.

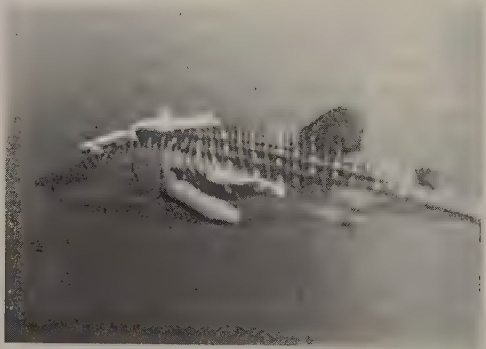
FIG. 4*f*. Whale shark accompanied by remora.

grouped as transients, visitors, or residents (Table 1) on the basis of their reaction to the raft and the length of time they remained near it. Transients (many of which were flyingfish, Exocoetidae) did not appear to react to the raft, but were usually visible only momentarily as they swam by. Visitors did not aggregate at the raft, but appeared to react to it; they usually remained near it for several minutes to an hour. Residents aggregated at the raft; some stayed in view more or less permanently, and others swam out of view for several hours but usually returned. Different individuals of certain species did not always react in the same way to the raft; these species were consequently placed in more than one category.

Residents were of two types: smaller fishes which stayed in the immediate vicinity of the raft and were usually in view of the observer; and large carnivores that were frequently out of view for several hours. When reappearing after a prolonged absence, the individual or group could often be identified by distinguishing characteristics such as abrasions, parasites, scars, the number in the group, and body size. The relation of all resident species to the raft was facultative, since each also occurs independently of any association with drifting objects.

Small resident fishes were: freckled driftfish, *Psenes cyanophrys* (Cuvier); juvenile pilotfish, *Naucrates ductor* (Linnaeus); rough triggerfish, *Canthidermis maculatus* (Bloch); scrawled filefish, *Alutera scripta* (Osbeck) (but only individuals exceeding about 20 cm, smaller ones behaving as visitors); amberjack, *Seriola rivoliana* Cuvier and Valenciennes; juvenile greater amberjack, *Seriola dumerili* (Risso); juvenile jack, *Caranx* sp.; adult and juvenile mackerel scad, *Decapterus pinnulatus* (Eydoux and Souleyet); juvenile skipjack tuna, *Katsuwonus pelamis* (Linnaeus); juvenile yellowfin tuna, *Thunnus albacares* (Bonnaterre); juvenile dolphin, *Coryphaena* sp.; and juvenile stages of four reef fishes—damselfish, *Abudefduf abdominalis* (Quoy and Gaimard); sea chub, *Kyphosus cinerascens* (Forskål); goatfish, *Mulloidichthys samoensis* Gunther; and squirrelfish, Holocentridae.

The large predatory residents were: dolphin, *Coryphaena hippurus* Linnaeus; wahoo, *Acanthocybium solandri* (Cuvier); rainbow runner, *Elagatis bipinnulatus* (Quoy and Gaimard) and whitetip shark, *Carcharhinus longimanus*, usually accompanied by adult pilotfish and remoras, *Remora remora* (Linnaeus).

The freckled driftfish was by far the most common resident in both drift areas. On all drifts it was the first to appear, had the highest rate of accumulation (Table 2), and attained the largest population. At the end of the second equatorial drift, 729 were caught in the purse seine and several hundred escaped. Many were also caught at the end of other drifts. Freckled driftfish usually came to the raft singly or in small groups. Once a green turtle, *Chelonia mydas*, came to the raft accompanied by nine driftfish and one remora. The turtle left with the remora after a few minutes, but the driftfish remained with the raft.

Residents accumulated more rapidly by day than by night. Statistics on the average rate of accumulation of some of the more common residents appear in Table 2. Less common residents, not listed in Table 2, also accumulated more rapidly by day than by night.

Species composition differed between the Hawaiian and equatorial areas. Only 38% of the 27 fish identified to species in Table 1 were seen in both areas. Three of the more common species off Hawaii, the rough triggerfish, dolphin, and damselfish, were either absent or rare in the equatorial waters. Of species that were residents at some stage in their life history, 62% were common to both areas, whereas none listed only as a visitor was common to both areas. Some of the apparent differences between the areas could have resulted from differences in the time of year or could even be attributable to the sample sizes. For example, the occurrence of rainbow runners, pompano dolphin (*Coryphaena equiselis* Linnaeus), and green turtles in the equatorial but not the Hawaiian area may well be irrelevant, for all are common in Hawaiian waters.

ADAPTIVE SIGNIFICANCE

Our observations provided relevant information on the hypotheses that floating material (1) provides protection from predators, (2) concentrates the food supply, and (3) acts as a cleaning station. These hypotheses, of course,

TABLE 1

ANIMALS SEEN FROM THE OBSERVATION CHAMBER OF A DRIFTING RAFT*

SPECIES, GENUS, OR FAMILY (Common Name in Parentheses)	DRIFT LOCATION	BEHAVIOR CATEGORY	FORK LENGTH (cm)	MAXIMUM NUMBER SEEN AT ONE TIME
Abudefduf abdominalis (damselfish)	H	R	0.7–1.0†	24
Acanthocybium solandri (wahoo)	H03	R	45–90	3
Alutera scripta (scrawled filefish)	H	RV	10–35	2
Canthidermis maculatus (rough triggerfish)	H	R	25–35†	33
Caranx kalla (golden jack)	H	V	30	1
Caranx sp. (jack)	H	R	2.9–5.3†	3
Carcharhinus longimanus (whitetip shark)	H03	RV	125–175	2
Chelonia mydas (green turtle)	0	V	60	1
Coryphaena equiselis (pompano dolphin)	03	V	30	100+
Coryphaena hippurus (dolphin)	H03	R	60–100†	70+
Coryphaena sp.	H03	R	10–15	80
Decapterus pinnulatus adult (mackerel scad)	H03	RT	20–25	1,000+
juvenile	3	R	13.1†	1
Diodontidae (spiny puffer)	0	V	12	1
Echeneidae (free-swimming) (remora)	3	R	8	1
Elagatis bipinnulatus (rainbow runner)	3	R	75	1
Exocoetidae (flyingfish)	H03	T	10–15	10+
Fistularia petimba (cornetfish)	H	V	20–40	2
Globicephala scammoni (pilot whale)	H0	V	375	2
Holocentridae (squirrelfish)	H	R	2	1
Istiophoridae (marlin)	H	T	125	1
Katsuwonus pelamis adult (skipjack tuna)	H3	T	45	1,000+
juvenile	3	RV	10–15	50
Kyphosus cinerascens (sea chub)	H	R	2.5†	13
Manta alfredi (manta ray)	H	V	100–125‡	1
Manta sp.	0	V		1

TABLE 1 (*continued*)

SPECIES, GENUS, OR FAMILY (Common Name in Parentheses)	DRIFT LOCATION	BEHAVIOR CATEGORY	FORK LENGTH (cm)	MAXIMUM NUMBER SEEN AT ONE TIME
Mulloidichthys samoensis (goatfish)	H	RV	10–12	1,000+
Naucrates ductor adult (pilotfish)	H03	RV	15–30	7
juvenile	H03	R	2.6–6.7†	7
Nomeus gronowi (man-of-war fish)	0	V	2	1
Prionace glauca (great blue shark)	0	V	150	1
Psenes cyanophrys (freckled driftfish)	H03	R	1.5–12.4†	1,000+
Remora remora (attached) (remora)	H03	RV	15–30	—
Rhincodon typus (whale shark)	3	V	300	1
Seriola rivoliana§ (amberjack)	H	R	20†	1
Seriola dumerili (greater amberjack)	H	R	3.7	1
Sphyraena barracuda (great barracuda)	H	V	50	1
Thunnus albacares (yellowfin tuna)	H3	RV	25–40	37
Tursiops sp. (bottlenose dolphin)	H0	V	150–200	20+

* Drift Location: H = Hawaii; 0 = 0° Latitude; 3 = 3° S.
Behavior Category: R = Resident; V = Visitor; T = Transient.

† Measured length; all other lengths are estimated.

‡ Breadth.

§ The first record for Hawaiian waters, identified by Dr. Frank J. Mather, Woods Hole Oceanographic Institution, from a specimen preserved after capture at the raft.

TABLE 2

AVERAGE NET INCREASE OR DECREASE IN NUMBER OF RESIDENTS* AT THE RAFT PER 12-HOUR DAY AND 12-HOUR NIGHT† IN THREE DRIFT AREAS
(Number of 12-Hour Periods in Parentheses)

	HAWAII OCTOBER 1962		HAWAII AUGUST 1965		0° LATITUDE FEBRUARY 1964		3° S MARCH 1964	
FISH	Day (9)	Night (7)	Day (8.5)	Night (4)	Day (7.5)	Night (9)	Day (8.5)	Night (9.0)
Psenes cyanophrys‡	24	1	107	1	18	1	100	0
Coryphaena sp. (juvenile)	–	–	–	–	11	−2	1	−1
Canthidermis maculatus	7	2	3	1	–	–	–	–
Coryphaena hippurus (adult)	4	1	10	0	–	–	–	–
Abudefduf abdominalis (juvenile)	4	−1	–	–	–	–	–	–
Decapterus pinnulatus (adult)	–	–	10	−5	2	0	3	−3
Katsuwonus pelamis (juvenile)	–	–	–	–	–	–	3	−3
Naucrates ductor (juvenile)	–	–	–	–	1	−1	–	–

* Only the residents with an average accumulation equal to or greater than one fish per 12 hours of daylight are included.

† Population changes during the night were estimated by comparing the last count in the evening with the first count the following morning.

‡ Increases are based on the rate for the first 100 to gather because larger numbers could not be counted accurately.

are not mutually exclusive. The observations provided less information about the other hypotheses mentioned earlier. All the above hypotheses consider the adaptive significance of floating material in the ecology of pelagic fishes. The stimuli that release the approach of fishes to the raft are not discussed.

Protection from Predation

At least nine species of fish, both large and small, reacted to the raft in a way that made them less vulnerable to predation. Typically, when a predator approached the raft, the prey formed a compact group very close to the understructure. When the predator left or ceased harassments, the prey again dispersed about the raft. Often the predator chased the prey to the raft. The value of the raft to the prey was demonstrated by the fact that only one species, the amberjack, frequently caught fishes that had taken shelter under the raft. Observations on individual prey species are described below.

The most common resident, the freckled driftfish, usually took a position far below and downwind from the raft and was sometimes out of view. Driftfish were able to match their background. They had a silvery countershaded coloration when not under the raft, but took on a mottled brown coloration when close under it, and those collected from under an orange drogue buoy had an orange color. Most of their predator-avoidance activity was in response to dolphins, although some was in response to pompano dolphins, wahoos, bottlenose dolphins (*Tursiops* sp.), or to pilotfish which approached the raft swimming with a whitetip shark. The hundreds of such responses followed an unvarying sequence: when one of the predators came into the vicinity, the freckled driftfish suddenly formed a compact school and swam rapidly back to the raft or the parachute drogue. (They also fled to the raft when an observer entered the water.) When an amberjack was preying upon them, they remained within about 20 cm of the viewing chamber. They attempted to stay on the opposite side of the chamber from the amberjack or dodged into the gaps between the frames of the viewing windows. When the amberjack was not actively feeding, the driftfish ranged out again. Small damselfish, pilotfish, greater amberjacks, and jacks behaved similarly to driftfish in response to predation, but did not change coloration.

Rough triggerfish ranged far from the raft, sometimes out of sight. Their rapid return to it usually heralded the appearance of a predator (billfish, a great barracuda, bottlenose dolphin, whitetip shark) or apparent predators (schools of mackerel scad or a powerboat). They resumed ranging before the potential predator departed, except when the predator was a bottlenose dolphin. None of the above species exhibited a predatory response towards rough triggerfish. The triggerfish did not return to the raft when manta rays appeared and they usually swam out and met approaching dolphins. Rough triggerfish and dolphins may often be associated in the absence of drifting material; sometimes they arrived simultaneously at the raft.

On several occasions, the most successful piscivore, the amberjack, itself became the potential prey of dolphins and took shelter beneath the raft. Although amberjacks frequently ranged 10 to 15 m from the raft unmolested, when the dolphin began pursuit the amberjack eluded the predator by swimming close to the chamber. It remained there for some time before ranging out again.

The dolphin, one of the largest residents, took shelter close under the raft three times: once in response to a bottlenose dolphin, once to a billfish, and once to a swimmer. Each time the dolphin swam around the chamber just under the flotation drums and took on a coloration (Fig. 5) that occurred in no other situation

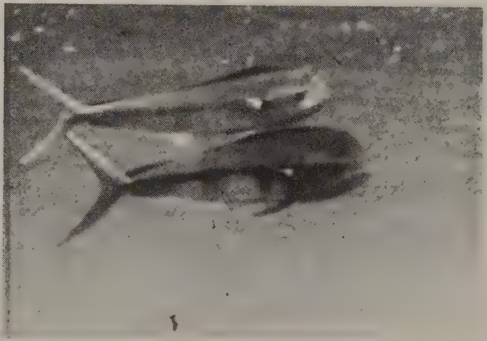

FIG. 5. The lower dolphin assumed the dark coloration when one of the observers entered the water.

and had not previously been recorded (for other colorations of this species, see Murchison and Magnuson, 1966). The dorsal half of the body turned a dark brownish-black. A sharp separation extended longitudinally along the side between the dark dorsal area and the silvery ventral half of the body. The above behavior and coloration, observed only when 1 or 2 dolphins were at the raft, were different from those seen on similar occasions when 13 or more dolphins were present. Then the group of dolphins swam immediately behind a billfish, a whitetip shark, bottlenose dolphin, and a swimmer near the raft. A position immediately behind a potential predator may be of advantage to the prey provided the animal has the speed and maneuverability to maintain such a position.

Large schools of goatfish attempted to avoid dolphins and amberjacks by swimming to the other side of the raft, but only rarely did individuals use the maximum shelter of the raft by swimming under it. As a consequence both predators were able to prey upon them successfully.

One of the most clearcut examples of predator avoidance occurred when a golden jack was chased to the raft by the feeding attacks of five dolphins. The dolphins stopped their feeding passes after the jack swam under the raft. For several hours the jack swam within inches of the chamber. The observer on deck could reach into the water and touch the fish without driving it away. After several hours it began to swim under the flotation drums, but not away from the raft. About 8 hours after it arrived the jack joined a whitetip shark and six pilotfish which swam close by, and left the raft in their company. The dolphins took on their feeding coloration, but did not attack the jack as it swam off with the shark. This incident provided evidence for the protective role that both floating objects and large animals such as sharks play for the fish that accompany them.

Concentration of Food Supply

It has often been said that floating material concentrates the food supply—smaller fish, zooplankton, or sessile biota. Most piscivores did not successfully prey on fish that sought shelter beneath the raft, but they did prey extensively on those that gathered at the raft but did not take shelter beneath it. Zooplankton was not concentrated at the raft, nor did large numbers of sessile organisms attach themselves to it.

Kojima (1956) suggested that dolphins were found near floating objects because more food was available there, but was unable to demonstrate that they fed substantially on other fishes gathered at anchored bamboo rafts (Kojima, 1960, 1961). Yabe and Mori (1950) argued that abundance of food was an inadequate explanation for the presence of yellowfin and skipjack tuna near floating logs because the fish took bait readily and did not have much food in their stomachs. The simultaneous presence of piscivores and potential prey near the raft was well documented, yet, as mentioned above, only amberjack successfully preyed on the small fish that took shelter there. We saw them chase and eat freckled driftfish. The stomach of the only amberjack taken at the raft contained three driftfish. The only other species we saw catch smaller fish was the adult dolphin. Both it and the amberjack, as has been mentioned, preyed on schools of goatfish that were near the raft, but not under it. The stomachs of 53 dolphins caught near the raft contained only 5 scrawled filefish; 1 sargassum triggerfish, *Xanthichthys ringens* (Linnaeus); and 1 puffer, *Diodon holocanthus* Linnaeus. All were juveniles. Once we saw an adult dolphin seize and eat a freckled driftfish which was attempting to reach the raft. This incident suggests that dolphins sometimes intercepted driftfish seeking shelter. Possible supporting evidence for this supposition came from observations off Hawaii. While the raft was anchored for several days, numerous freckled driftfish, 19 dolphins, and 1 amberjack accumulated. The raft was then towed by the ship 30 miles down the coast and set adrift. During the tow the driftfish were outdistanced and all were lost; only the dolphins and amberjack remained. Thus, unlike other drifts, this drift began with a number of fish—19 dolphins and 1 amberjack—at the raft. During 52 hours of drifting no freckled driftfish appeared. Yet in the same area, two weeks earlier, approximately 500 and 200 driftfish gathered at the raft on two drifts of 50 and 32 hours, during which only 2 and 7 dolphins had accumulated.

Two other predators, wahoos and adult pilotfish (with sharks), actively chased smaller fishes at the raft, but were not observed to catch any.

Although zooplankton was not concentrated at the raft, a number of fishes that eat zooplankton gathered there. For example, stomachs of 10 rough triggerfish caught at the raft contained many pteropods and stomatopods, and lesser numbers of crab megalops and zoea, amphipods, and copepods. Stomachs of 81 freckled driftfish contained small pelagic tunicates (*Oikopleura* sp.), copepods, fish eggs, chaetognaths, and various coelenterates. These fish also bit at macroplankton such as ctenophores and tunicate colonies. Stomachs of 24 damselfish contained only *Oikopleura* sp. Stomachs of nine small pilotfish contained mostly copepods. All of these fishes, and also scrawled filefish and goatfish, frequently darted after and caught zooplankton around the raft. The wind slowly pushed the raft through the water at a speed faster than the swimming speed of the small zooplankters. Thus, there was no accumulation of zooplankton, but rather a continuous stream of macroplankton and microplankton slowly moving past the underwater windows.

Finally, fishes at the raft did not feed on the small amounts of sessile or ambulating biota present. Only the rough triggerfish bit at the raft. Crab megalops occasionally settled on the underside of the raft or on the triggerfish, but those in the stomachs could have been taken as well from the plankton as from the raft. Perhaps a greater growth of biota on the raft would have altered the feeding behavior, especially of the triggerfish, which has a dentition suited for grazing. Evans (1955) reported that triggerfishes (*Balistes* sp., and *Canthidermis* sp.) cropped barnacles fringing the waterline of a drifting vessel in the Atlantic North Equatorial Current.

Removal of Ectoparasites

At the beginning of this study we hypothesized that floating objects serve as cleaning stations where fishes may gather to have parasites removed by other fish. Many fish observed at the raft carried ectoparasites, and several events suggested that these were eaten by other fish. Fish also chafed against the raft, another possible aspect of cleaning behavior.

Small copepods were found on captured dolphins, freckled driftfish, and rough triggerfish, and were seen on whitetip sharks and juvenile dolphins (*Coryphaena* sp.). Crab megalops and parasitic isopods were also seen on triggerfish. The megalops walked freely over the fish; the isopods were firmly attached.

Biting behavior was common among rough triggerfish and was directed toward a triggerfish that was headstanding (body oriented head down), apparently soliciting predation on parasites. This behavior occurred only when more than one triggerfish was present; it was common 3 to 12 m from the raft. The headstanding fish did not flee the biting fish and once even appeared to rotate its body, keeping the side with the parasitic isopod toward the biting fish. The biting was always directed at the headstanding fish even though several other fish were very close by. Although we did not witness directly the removal of a parasite, we saw one rough triggerfish bite at a parasitic isopod on the caudal peduncle of another, and soon afterward the isopod was missing. Biting did not appear to represent aggressive behavior; intraspecific aggression among triggerfish frequently occurred immediately under the raft, but did not include headstanding. In aggression one triggerfish repeatedly chased others from under the raft.

Once a rough triggerfish swam to a dolphin and apparently nipped at it. The dolphin, some distance from the raft, had begun leaning to one side. It had also stopped swimming and was almost motionless in the water. It leaned four times within 2 minutes, for periods of about 9 seconds. Similar leaning behavior by dolphins in the presence of rough triggerfish was seen on several other occasions, but did not elicit nipping by the latter. This behavior was not unlike that of inshore fishes soliciting parasite-cleaning labrids (Randall, 1958). Balistids are not among the reported inshore parasite-pickers, but their dentition should make them efficient in this role.

A juvenile dolphin, *Coryphaena* sp., with a small reddish copepod attached near the fork of the caudal fin repeatedly positioned itself so that its caudal fin was close to the head of

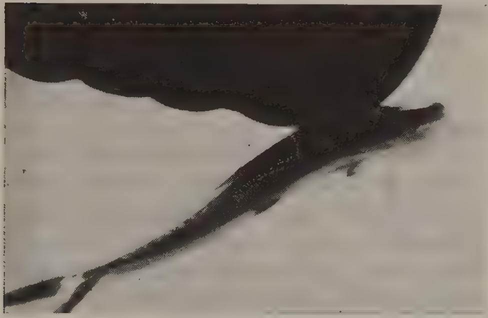

FIG. 6. Adult dolphin chafing against a 55-gallon drum beneath the raft.

another juvenile dolphin, *Coryphaena* sp. During the display the fish with the ectoparasite stopped caudal movements and treaded water with its pectorals. It did not lean to one side as did the adult dolphin mentioned above. On numerous occasions, the juvenile dolphin, *Coryphaena* sp., to which the display was directed made passes at the caudal fin of the parasitized fish. At the end of the day, however, the copepod was still attached.

Several species chafed their sides on the raft, skiff, or lines hanging in the water. Adult dolphin commonly chafed against the bottom of the raft and skiff (Fig. 6). Sanchez Roig and Gomez de la Maza (1952) and Heyerdahl (1950) have reported similar behavior. Sometimes dolphin chafe against other fish (Breder, 1949). In one of our film sequences, a small abrasion can be seen on the side that the fish was rubbing against the skiff. Other species at the raft which were seen chafing were rough triggerfish on the bottom of the raft; juvenile dolphin on ropes and on the caudal and dorsal fins of whitetip shark; whale shark, whitetip shark, and scrawled filefish on the rope to the parachute drogue; and a spiny puffer, on a small floating can. This behavior, especially common in the coryphaenids, could remove parasites or relieve skin irritation.

Some predation on ectoparasites occurred at the raft, but the question remains whether the removal of parasites is concentrated near the raft and other floating objects. It is obvious that removal of parasites by chafing on hard objects would be concentrated near floating material or larger fishes. In addition, the opportunity to feed on ectoparasites or to solicit parasite cleaning would appear to be greater near the raft because the fishes usually arrived in small groups or alone and formed larger aggregations at the raft.

Other Possible Explanations

The hypothesis that fishes seek shade under floating objects has no substance. Yabe and Mori (1950) and Kojima (1956) also reached this conclusion. None of the smaller species tended to remain in the shade of the raft. Larger species such as rough triggerfish, wahoo, dolphin, and whitetip shark often ranged far from the raft and were seldom in its shadow. The hypothesis (Besednov, 1960) that fish use floating material as a substance on which to lay their eggs could not be substantiated. Even though fish eggs are frequently found on drifting material, no fish deposited eggs on the raft nor were any eggs seen on the undersurface. No data were obtained to test the hypothesis (Damant, 1921) that the shadow of an object makes the zooplankton more visible to fish. Four species fed upon zooplankton; the visibility of these zooplankters may have been increased by the raft's shadow.

CONCLUSION

A floating object in the pelagic environment provides a relatively rare "superstrate" in an environment notable for its horizontal homogeneity. This superstrate has some of the same ecological significance to certain pelagic fishes that a substrate has to inshore fishes. Obviously, no single biological association or adaptive advantage can explain the occurrence of fish around floating objects at sea. Of the ecological hypotheses considered, shelter from predation is substantiated best and appears to be the most significant factor in the evolution of fish communities that gather beneath inanimate drifting material in the open ocean.

ACKNOWLEDGMENTS

We thank Randolph K. C. Chang, Robert T. B. Iversen, and Everet C. Jones, Bureau of Commercial Fisheries Biological Laboratory, Honolulu, who assisted in making the observations; Frank J. Mather, Woods Hole Oceanographic Institution, who verified the new record for Hawaii of *Seriola rivoliana;* John E. Randall, The Oceanic Institute and the Bishop Museum, Honolulu, Howard E. Winn, University of Rhode Island, Philip Helfrich, University of Hawaii, Thomas A. Manar, and Donald W. Strasburg, Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Charles M. Breder, Jr., American Museum of Natural History, and John H. Hunter, Bureau of Commercial Fisheries Tuna Resources Laboratory, La Jolla, California, who reviewed the manuscript during various phases of its development.

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Reprinted from Activities Report, Spring 1967, Vol. 19 No. 1, Pages 5–13

Recent Trends in the Fisheries of the Northwest Atlantic

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The rapidly expanding world population is making increasing demands on the world's food-producing resources. As the pressure builds up, world nutritionists look more and more toward the ocean to fill this need, especially for high protein foods for which the ocean is noted.

Marine resources, fortunately, are renewable; but, unfortunately, they are not inexhaustible. There is some finite maximum amount that can be harvested annually on a sustained basis. The determination of the value of this maximum is a problem for fishery scientists. So far, those who have been courageous (or foolish) enough to attempt an estimate of potential world production have not been in general agreement. Graham and Edwards (1962) concluded that we cannot expect to increase world production of marine fishes by more than two or three times present production, but Schaefer (1964) placed this factor at five times, and Chapman (1966) stated that we are presently taking only 5 percent of the maximum sustainable yield of all the living resources which the ocean is capable of producing. In any case, some parts of the world's oceans appear to be producing near their maximum potential already. The Northwest Atlantic is one of these, and it is the purpose of this paper to review recent trends in production from this area.

World fishery statistics are compiled by the Fisheries Department of the Food and Agriculture Organization of the United Nations and are published annually in the FAO Yearbook of Fishery Statistics. FAO divides the world oceans into 14 statistical areas, one of which coincides with the Convention Area of the International Commission for the Northwest Atlantic Fisheries (Figure 1), a commission organized in 1951 to insure the maximum sus-

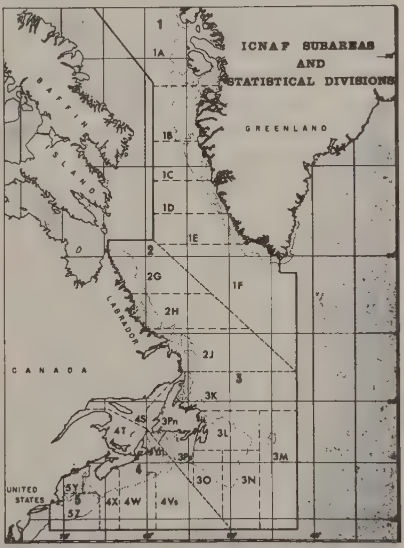


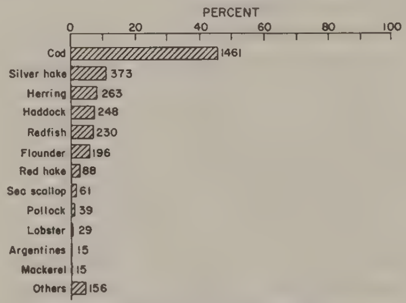
Figure 1. The Conventional Area of the International Commission for the Northwest Atlantic Fisheries.

tainable yield from the area (Anonymous, 1951). The latest available FAO Yearbook (1964a) shows the total 1964 catch of fish and other products from the waters of the world as 51.6 million metric tons, of which 45.0 million metric tons came from the ocean (40.5 million metric tons of finfish, the rest crustaceans, molluscs, mammals, and other forms).

Fully a quarter of this total world production of marine finfish is provided by the fishery for a single species, the anchoveta of Peru and Chile, the landings of which amounted to 10 million metric tons in 1964. This catch is reduced to meal and oil; the meal is exported to the United States and other developed countries of the world for the production of poultry and other farm stock. Of the remaining 30.5 million metric tons, about 10 million metric tons were taken from the Western-Central Pacific by Japan and other Asiatic countries; 4.8 million metric tons from the North Pacific; 8.5 million metric tons from the Northeastern Atlantic; and 2.9 million metric tons from the Northwestern Atlantic, the area with which we are concerned today. The remaining 4.3 million metric tons came from the other nine statistical areas. Statistics now available for the Northwest Atlantic show that the catch increased to 3.2 million metric tons in 1965. The Northwest Atlantic is a rich fishing region. Although its surface area represents only about one-half of one percent of that of the world's oceans, its production of 3.2 million metric tons is 11 percent of world production of marine fish for direct human consumption (FAO, 1964b).

Almost all of the catch in the Northwest Atlantic is in the form of prime high grade fish in great demand as human food; very little is reduced to meal and oil or processed for food of pets or fur animals. The species concerned are cod, haddock, silver hake, red hake, herring, redfish, yellowtail and other flounder, sea scallops, lobsters, and a host of others (Figures 2 and 3).

The Northwest Atlantic has been a busy fishing ground for hundreds of years. The cod fishery of the Grand Bank was developed by French fishermen as far back as the 16th Century, and salt cod from the area was an important article of trade for Canada and the United States for centuries. Many changes



Landings from the Northwest Atlantic in 1965, by species (thousands of metric tons, live weight).

Figure 2. Landings from the ICNAF Convention Area by species.

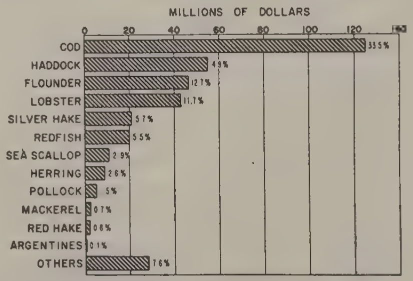


Figure 3. Value of landings from the ICNAF Convention Area by species.

have taken place in the fisheries of the Northwest Atlantic since those early days, but the quantity of fish removed annually has steadily increased. Sail has given way to steam and oil, hook and line to otter trawls, salting has been replaced by freezing and canning, but the fishing effort has intensified. As cod failed to keep up with the increasing demand, effort was turned to other species such as haddock and redfish, and then herring and hakes. As the European nations developed larger vessels that could remain at sea for months at a time, they moved farther and farther south until they arrived on Georges Bank, off Cape Cod, which until 1961 was fished only by U.S. fishermen. Although the Northwest Atlantic has seen fishermen from a few European countries since the beginning of recorded history, the number of countries fishing in the area has increased in recent years until we can now count more than 15.

In analyzing the landings statistics for the Northwest Atlantic in recent years, two things stand out clearly. First, total production has increased markedly in the last 6 years and second, the U.S. fishermen have not shared in this increased productivity; in fact, their tonnage has dropped in spite of the advantage they enjoy in proximity to the fishing banks.

It is a sad commentary on world economics that foreign fishermen catch fish off our shores, frequently fishing alongside our own fleet; land and process the fish in their own countries; and export it to the United States in direct competition with our own product. Although the consumption of fish and fishery products in the United States is steadily increasing, the landings of U.S. fishermen is steadily declining. This is true not only for the Northwest Atlantic but for the country as a whole. It is estimated that the total U.S. catch in 1966 will be the lowest since 1942.

In the Northwest Atlantic the total landings by all countries increased from 1.8 million metric tons in 1955 to 3.2 million metric tons in 1965, but the U.S. catch dropped from 550 thousand metric tons to 326 thousand metric tons and its percentage of the catch dropped from about 27 to 10 (Figure 4).

Figure 5 shows the amount taken by each of the more than 15 nations fishing in the Northwest Atlantic in 1965. Canada has for many years been the leading nation in this area, with the United States close behind. When the USSR came into the area, she rapidly expanded her fishing fleet. Her catch exceeded that of the United States in 1963, which put her in second place behind Canada. She is now a good prospect for first place. Her catch in 1965 exceeded that of Canada in 1964,

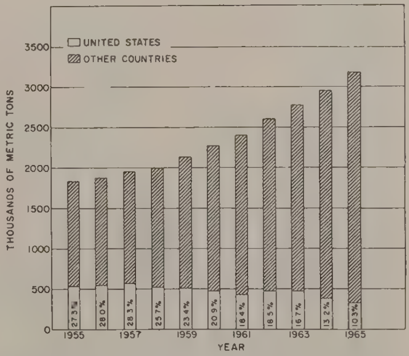
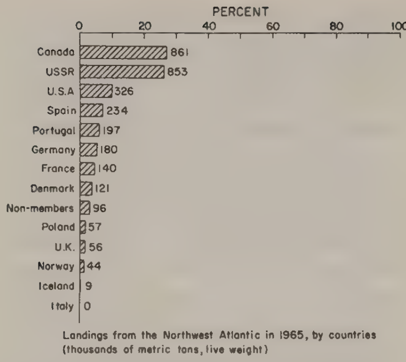


Figure 4. Landings from the ICNAF Convention Area by the United States and by all other countries.



Landings from the Northwest Atlantic in 1965, by countries (thousands of metric tons, live weight)

Figure 5. Landings from ICNAF Convention Area by country.

but Canada's own increase in 1965 kept her slightly in the lead for that year.

Georges Bank, off Cape Cod, is one of the richest banks in the world. Until 1961 this area was virtually a U.S. preserve. Canada took a few haddock and sea scallops. Since 1960, Canada and more particularly the USSR, have increased their catches from this area (Convention Subarea 5); in 1965 the U.S. catch represented only 32 percent of the total—and these are the grounds closest to the U.S. fishing ports (Figure 6).

Haddock is the most valuable species of the area to the United States and most of it is taken from Subarea 5. Figure 7 shows what dramatic changes took place in this fishery in 1965. A very large year class, that of 1963, was recruited to the fishery in the fall of 1965 as small fish. It was so abundant that it attracted the attention of the Soviet fleet with the result that the Soviets removed 82 thousand metric tons of haddock from the subarea in 6 months of fishing. The United States removed only 55 thousand, Canada 15 thousand. The total catch from Georges Bank in 1965 was the largest ever recorded, but the U.S. catch was about average for the past 20 years.

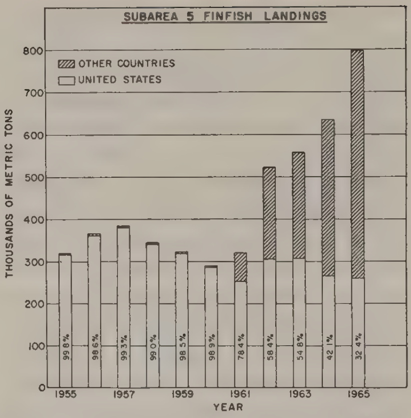


Figure 6. Finfish landings from ICNAF Subarea 5 by the United States and by all other countries.

Cod is becoming of decreasing importance to the United States but the total from the Convention Area is increasing (Figure 8).

Silver hake is used in the United States for both human food and for reduction to meal and oil. Although it is a very abundant fish, it was taken only by the United States before 1962. The Soviet catch now is 7.5 times that of the United States and most of this is prepared for human consumption (Figure 9).

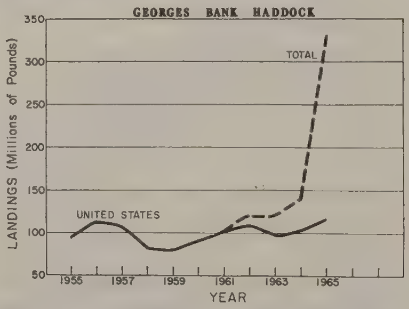


Figure 7. Haddock landings from ICNAF Subarea 5 (Georges Bank) 1955–1965.

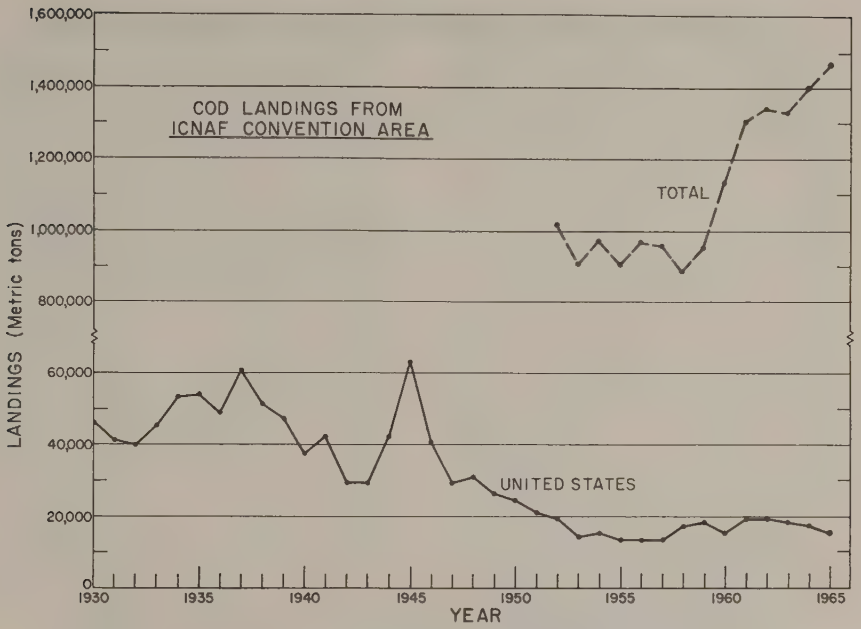


Figure 8. Cod landings from the ICNAF Convention Area, 1930–1965.

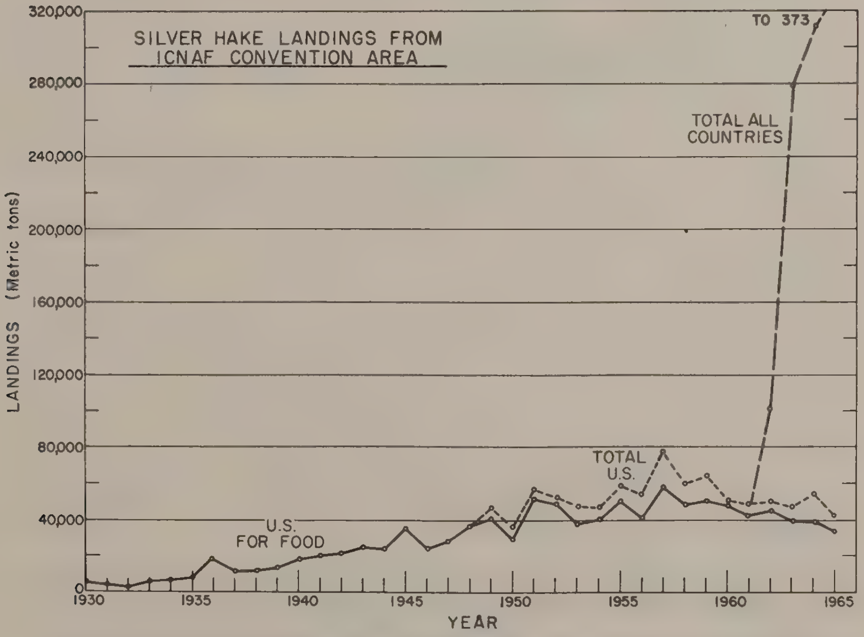


Figure 9. Silver hake landings from the ICNAF Convention Area, 1930–1965.

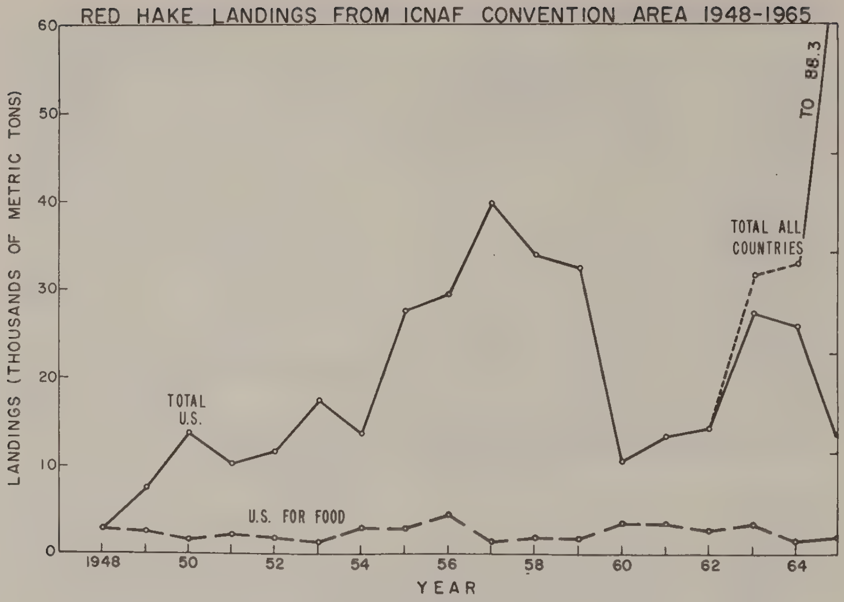


Figure 10. Red hake landings from the ICNAF Convention Area, 1948–1965.

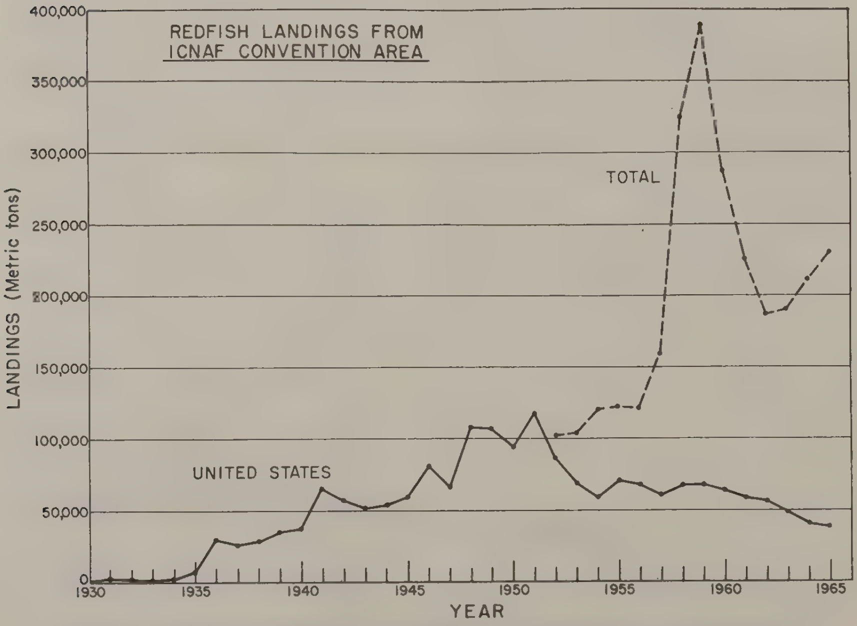


Figure 11. Redfish landings from the ICNAF Convention Area, 1930–1965.

Red hake has been used in the United States primarily for meal and oil and the landings reflect the changing fortunes of the meal industry (Figure 10). The Soviets discovered this species and removed an amount double ours in 1965.

Redfish landings (Figure 11) follow the general trend of decreasing U.S. landings in the face of increasing removals from the Convention Area.

Yellowtail flounder, the fourth most valuable species to the New England fishermen, is still essentially an exclusive U.S. fishery, at least in its main area of distribution, the southern part of the Convention Area. For the Convention Area as a whole (Figure 12) there is some evidence that foreign interest is developing in this species.

Herring landings (Figure 13) are another example of recent trends. Canada and the Soviet Union are the prime competitors for this species.

Sea scallops are the third most valuable species in terms of New England landings. They are taken by only two countries, Canada and the United States. Significantly, the Canadian landings have equaled our own in recent years and in 1965 far surpassed ours in the Convention Area (Figure 14). In 1965 both countries fished south of the Convention Area and the total Canadian catch equaled our total catch. The peaks in the catch curves for the Convention Area are due to unusual abundance of scallops in the early 1960's.

The greatly intensified effort brought into the Northwest Atlantic has raised the serious question of overexploitation. Fortunately, the countries interested in the area had some years ago agreed upon a study of this problem through the organization of the international commission so that the mechanism for such a study is already at hand. Biologists from the member countries have

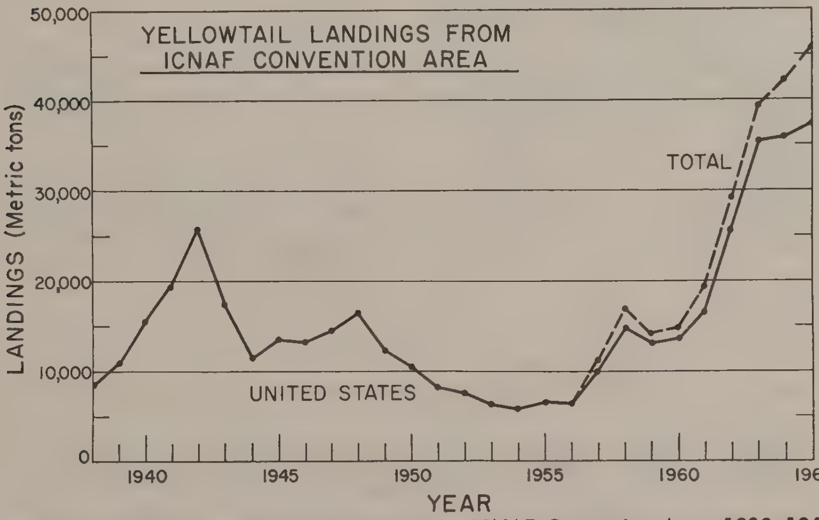


Figure 12. Yellowtail flounder landings from the ICNAF Convention Area, 1938–1965.

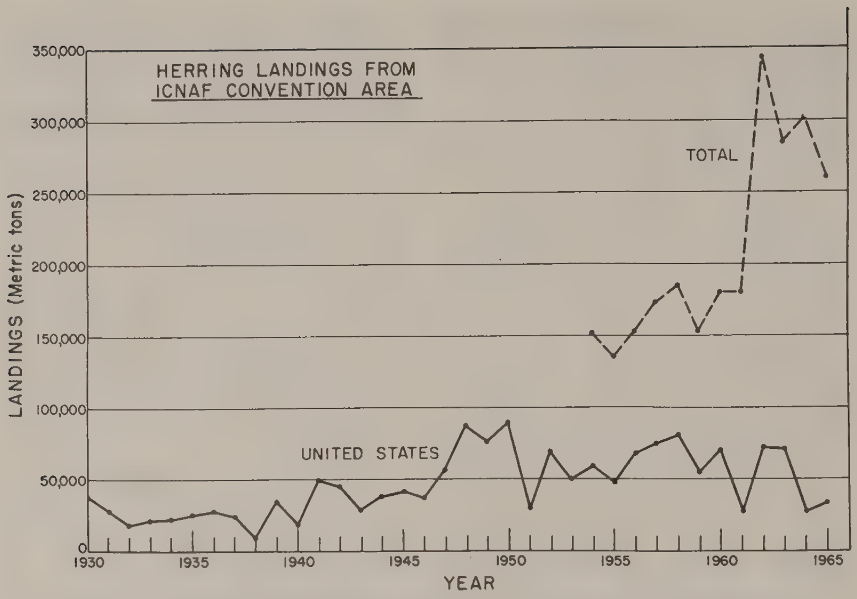


Figure 13. Herring landings from the ICNAF Convention Area, 1930–1965.

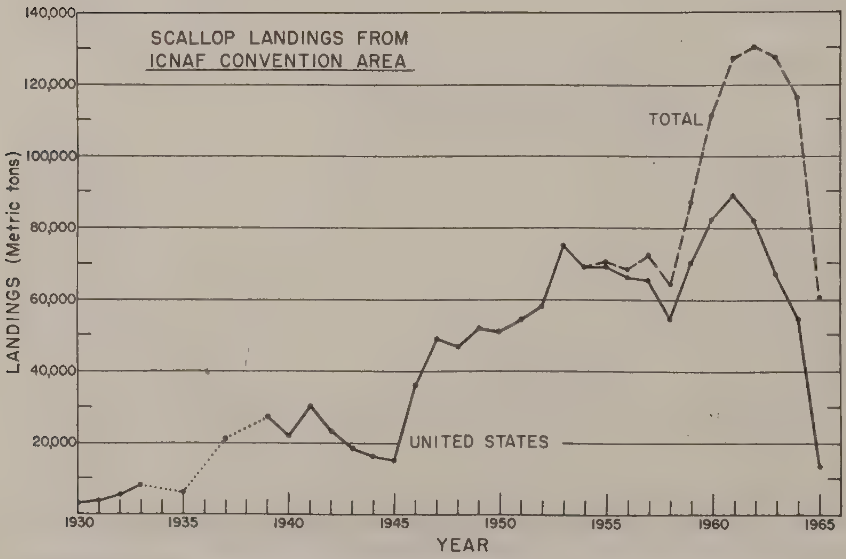


Figure 14. Sea scallop landings from the ICNAF Convention Area, 1930–1965.

developed a program of fishery research which is being regularly pursued by the member countries; their efforts are coordinated through the Commission's headquarters and international advisory committees composed of scientists of member countries.

The scientists are addressing themselves to this very question of exploitation rate and maximum potential yield of the fisheries of the Convention Area.

In the early days of the Commission in the 1950's the scientists stressed mesh regulation as a means toward protecting the fish stocks against intensive fishing and to insure a maximum sustainable yield. Such regulations, which are now in effect in the Convention Area, protect the small fish and allow them to survive a while longer and increase in weight before they are caught to contribute to the total biomass of landings.

Cod and haddock have had this protection for several years, but as the fleets expand and the effort increases it becomes evident that mesh regulation alone will not insure continued high landings. Present opinion is that some of the important species such as cod and haddock are now producing at or near their maximum and that further increases in effort will not result in increased landings and may, in the long term, bring decreases.

Our conclusion at the moment is that the Northwest Atlantic on the whole is in a heavily exploited state and that we cannot expect any substantial increases from the area in the future. The yields of some species such as redfish and herring can probably be increased, but the total of all species is not likely to rise more than 10 or 20 percent under the most intensive exploitation and diversification of catch. If world production of marine fishery products is to increase to meet the protein needs of an expanding world population, the major part of the increases must come from other, less exploited areas.

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Reprinted from Recent Developments and Research in
Fisheries Economics, The New England Economic
Research Foundation, 1967

THE OFFSHORE RESOURCES OF THE NORTHWEST ATLANTIC

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The Northwest Atlantic is one of the richest fishing areas of the world. Favorable hydrographic conditions over broad expanses of the continental shelf result in high organic production which supports an abundance of fish that have been in great demand by man for hundreds of years. The landings from the Northwest Atlantic have been an appreciable part of world marine fish production since the discovery of America.

Reliable statistics are not available for the early years, but we know that in 1930 the catch of cod alone in the Northwest Atlantic, amounting to 56,600 metric tons, was over 5% of the entire world production of all fish, freshwater and marine.[1] By 1954, when world landings of marine fishes had increased to 23 million metric tons, the Northwest Atlantic catch amounted to 1.8 million metric tons or 8%; and in 1964 the catch of 2.9 million metric tons from the Northwest Atlantic was still 7% of the 44 million metric ton world total of marine fishes.[2]

In the early days of the Northwest Atlantic fishery, cod accounted for most of the catch. Today, it is still the leading species in terms of pounds landed, but many other species of groundfish, pelagic fish, and shellfish are taken as well. The present composition of the catch is shown in Table 1.[3]

[1] *Statistical Bulletin*, Vol. 2 (1952), International Commission for the Northwest Atlantic Fisheries. Also see George Borsstrom, *Fish as Food*. Vol. I (Academic Press, 1961).

[2] *Statistical Bulletin*, Vol. 14 (1964), International Commission for the Northwest Atlantic Fisheries (In Print). Also see *Year Book of Fishery Statistics*, Vol. 17 (1964), Food and Agricultural Organization of the United Nations.

[3] All statistics presented in tables and charts in this paper are from the Bureau of Commercial Fisheries and *Statistical Bulletin*, ICNAF.

TABLE 1

LANDINGS FROM THE NORTHWEST ATLANTIC IN 1964,
BY SPECIES (THOUSANDS OF METRIC TONS, LIVE WEIGHT)

Species	Landings	Percent
Cod	1,402	47.5
Silver hake	302	10.2
Herring	302	10.2
Redfish	213	7.2
Flounder	148	5.0
Haddock	142	4.8
Sea scallop	117	4.0
Pollock	44	1.5
Red hake	32	1.1
Lobster	30	1.0
Argentines	18	0.6
Mackerel	13	0.4
Squid	11	0.4
Other species	177	6.1
Total	2,951	100.0

The fishery of the Northwest Atlantic has been international since its inception at the time of the discovery of America, and has become even more so during the last decade. Portuguese and French cod fishermen of the North Atlantic extended their activities to the Grand Bank of Newfoundland before the continent was settled. Others followed until today 11 European countries and Japan fish side by side with Canadian and U.S. fishermen. Table 2 presents the distribution of the catch by country for 1964. For a long time the intensive fishery was concentrated on the Grand Bank, but today European fleets are working as far south as Georges Bank off Cape Cod and even farther south along the Atlantic Coast.

This increased fishing effort by European nations has increased total production from the area. U.S. production, on the contrary, has declined somewhat and the U.S. percentage of the total has dropped from more than 28 to about 13 in the last 6 years (Figure 1).

Figure 1

LANDINGS FROM ICNAF CONVENTION AREA

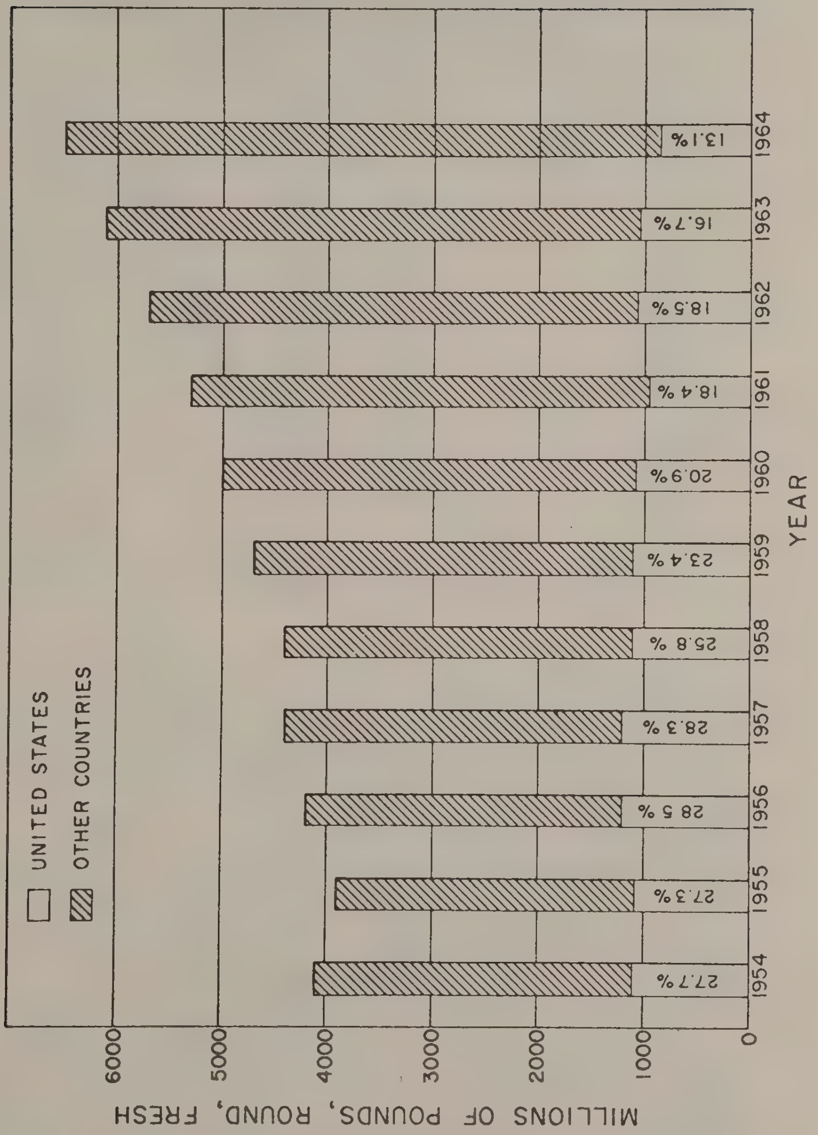

TABLE 2

LANDINGS FROM THE NORTHWEST ATLANTIC IN 1964, BY COUNTRY
(THOUSANDS OF METRIC TONS, LIVE WEIGHT)

Country	Landings	Percent
Canada	827	28.0
USSR	617	20.9
USA	388	13.1
Spain	231	7.8
Portugal	210	7.1
France	160	5.4
Germany	149	5.1
Denmark	127	4.3
Nonmembers of ICNAF	95	3.2
UK	52	1.8
Norway	50	1.7
Poland	37	1.3
Iceland	8	0.3
Italy	0	0.9
Total	2,951	100.0

Realizing the increasing intensity of fishing and fearing that overexploitation might operate to the detriment of the catches, the countries fishing in the Northwest Atlantic in 1949 signed a convention which resulted in the implementation of the International Commission for the Northwest Atlantic Fisheries (ICNAF). This Commission held its first annual meeting in 1951. The purpose of the Commission is to investigate, protect, and conserve the fisheries of the Northwest Atlantic Ocean "in order to make possible the maintenance of a maximum sustained catch from those fisheries."[4]

Estimation of the resource base in the Convention Area, which extends from Greenland to Rhode Island (Figure 2) is, of course, one of the prime responsibilities of ICNAF scientists. One of the first activities of the Commission was the compilation and publication of detailed statistics on the catch and on the activities of the various fishing fleets in the area. We now have available on an annual basis information on catch and effort which can be used for

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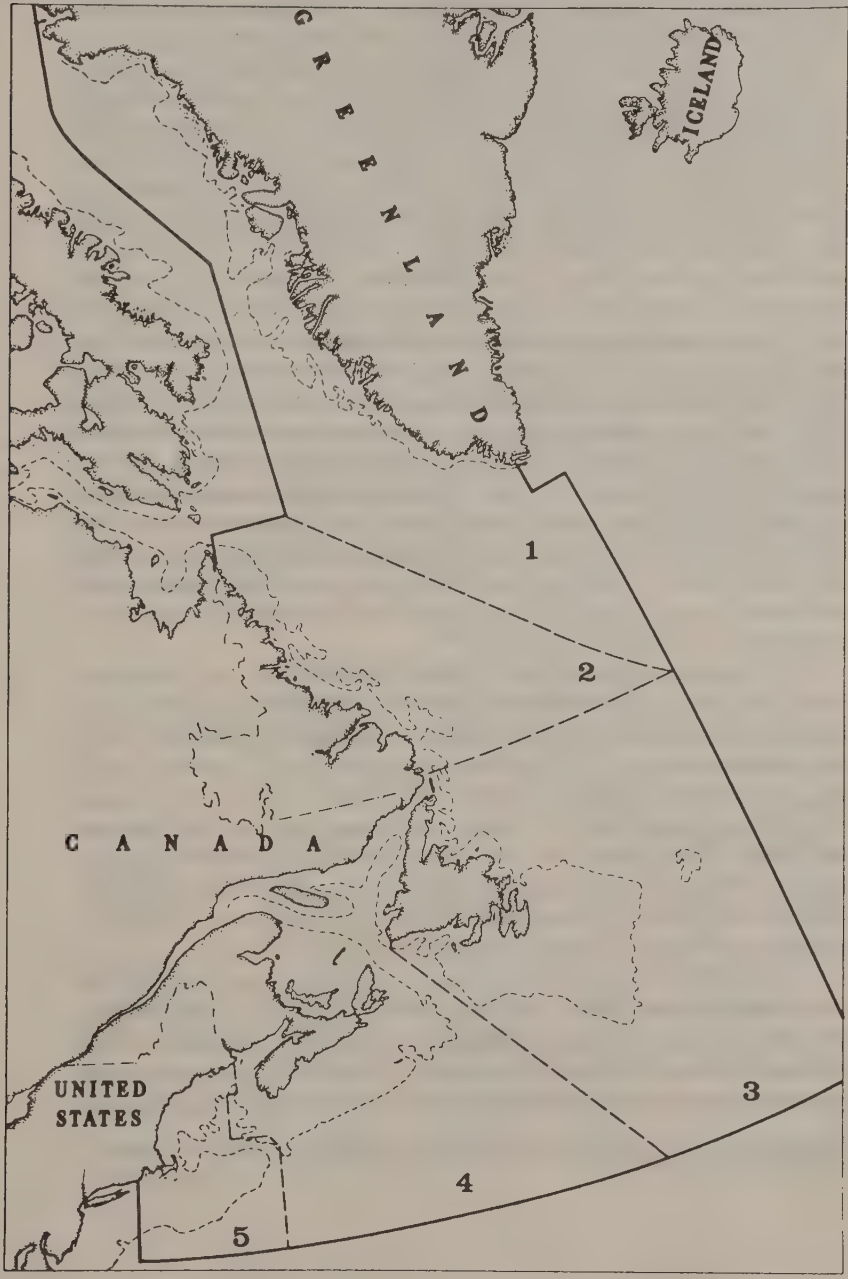
[4] *Report of the First Annual Meeting*. Report No. 1, International Commission for the Northwest Atlantic Fisheries (1951).

Figure 2

CONVENTION AREA OF THE INTERNATIONAL COMMISSION OF THE NORTHWEST ATLANTIC FISHERIES, SHOWING THE FIVE SUBAREAS


GREENLAND
ICELAND
1
2
3
4
5
CANADA
UNITED STATES

recommending regulations. Early in its history, the Commission imposed minimum-mesh regulations in certain subareas and it is now considering other management measures. Central to all these considerations is the size of the resource and the tonnage of fish which we can hope to take from the area on a sustained basis.

Since many species are involved in the fishery and different stocks of each species occupy different areas, the estimation of sustained yields is complicated. ICNAF scientists have been studying this problem for many years, however, and have arrived at some rather general conclusions. They have some broad estimates of where we are at present on the yield-effort curve, even though they have not, as a rule, indicated a sustainable yield figure for particular stocks. One of the difficulties, of course, is the great variation in recruitment which occurs in most stocks and the fact that we do not understand what relationship, if any, stock size has to recruitment.[5] The general conclusion, however, is that fishing effort in the Convention Area has reached a point where many stocks are now producing at the maximum level and that further effort would not increase the sustainable yield, but might, in fact, result in lower long-term yields. These conclusions relate primarily to stocks which have been traditionally fished for many years, such as the Grand Bank cod and the Georges Bank haddock. If we consider all stocks, including some that are underfished, such as the red hake, it is probable that present total landings are about 20% under total sustainable tonnage.

To present a general idea of the magnitude of each important stock of fish in the offshore waters of the Northwest Atlantic, a series of landing statistics are shown in Tables 3 to 13. The statistics, broken down by ICNAF Subarea (see Figure 2), present values for all countries combined and for the United States alone. Under the column "high year" is given the tonnage for the highest year on record. The figures for the "low year" are for the lowest year since ICNAF statistics became available in 1951. The average for 1952-64 and the figure for 1964 are useful in appraising present exploitation in relation to sustainable yield.

The figures on sustainable yield are given only for cod, haddock, redfish, yellowtail flounder, silver hake, red hake, herring and sea scallops. Adequate information is lacking on which to base estimates of yields for the other species. The sustainable yield figures presented here were arrived at by a study of growth rates, mortality rates, and a time series of effort-catch per effort relations; they assume average, long-term recruitment. Admittedly, they are estimates and subject to change, but they are based on scientific judgment. It must be stressed that because long-term, average recruitment is assumed, the sustainable yield figures are long-term averages in themselves. Recruitment is notoriously variable. When recruitment is high, stock size increases and the yield for a few years may be much higher than the long-term sustainable yield. Indeed, in an ideal management program the yield should be allowed to increase under these circumstances. Conversely, when recruitment is low and the stock size diminishes, yields should be kept at a lower level.

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[5] Recruitment is that increment to the fish population resulting from increased survival over a period of time.

Cod

Cod, the old standby of the Northwest Atlantic fisheries, has in the last few years provided greater tonnage than ever before, although the U.S. catch has not increased and has been below the levels of former decades (Figure 3). It is probable that the species is being fished too intensively on the Grand Bank (Subarea 3) although maximum yields are probably not being reached south of that area except on Georges Bank (Subarea 5), where annual landings in recent years have been near the estimated maximum sustainable yield (Table 3).

TABLE 3

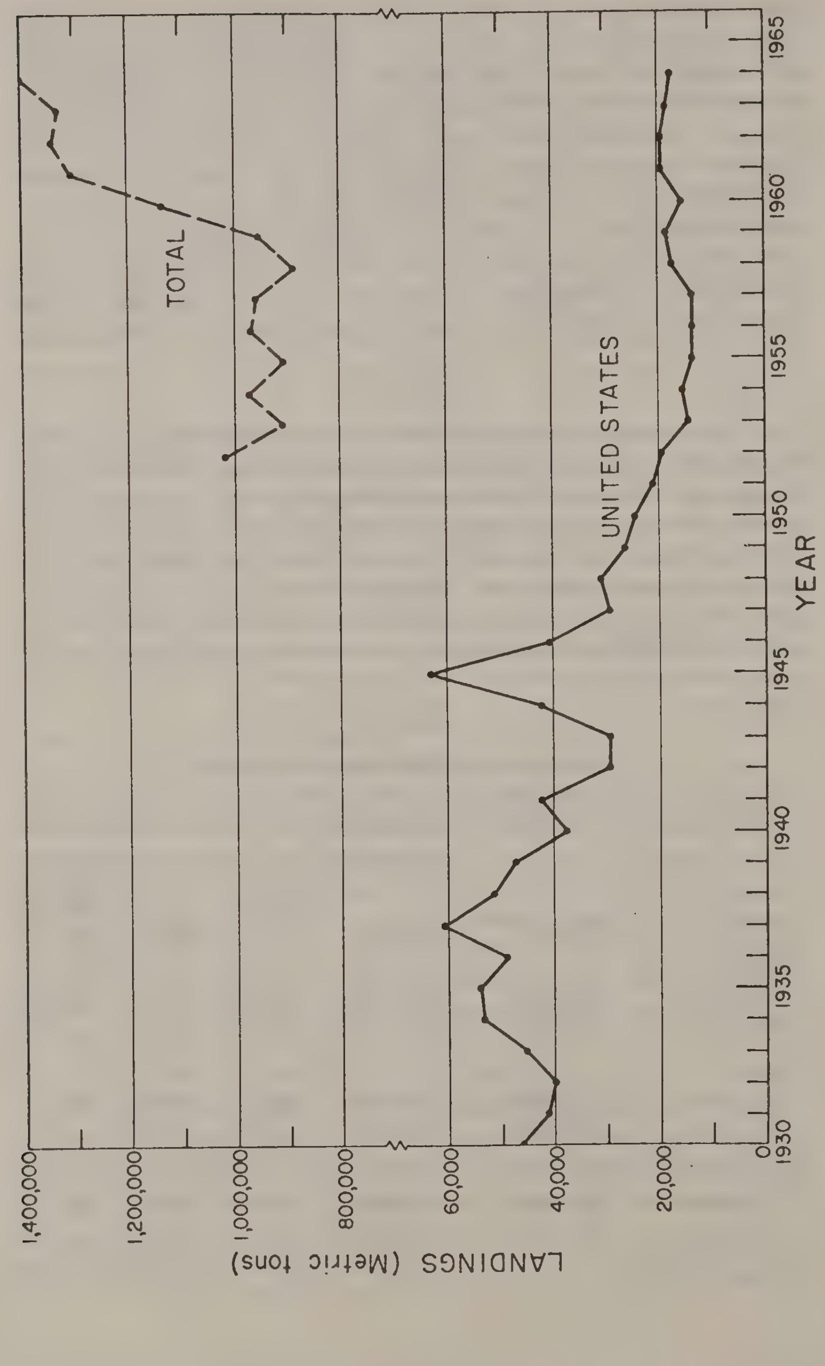
COD STATISTICS, ICNAF CONVENTION AREA
(Thousands of Metric Tons, Live Weight)

Locality of fishing	Landings				Estimated sustainable yield
	High year	Low year	Average 1952-1964	1964	
Subarea 3					
All countries	581.4 (1964)	328.0 (1952)	423.6	581.4	400
U.S.	23.8 (1895)	0[1]	0.2	0	–
Subarea 4					
All countries	229.0 (1964)	132.0 (1952)	192.2	229.0	250
U.S.	43.9 (1945)	1.3 (1963)	2.4	1.4	–
Subarea 5					
All countries	63.7 (1895)	11.2 (1953)	17.2	28.4	25
U.S.	63.7 (1895)	11.2 (1953)	14.7	15.6	–

[1] During World War II.

Figure 3

COD LANDINGS FROM ICNAF CONVENTION AREA



Silver Hake (Whiting)

Until 1962 silver hake was taken only by the United States. In that year the USSR started intensive exploitation and the catch skyrocketed (Figure 4). The United States lands this species both for food and for industrial purposes. The United States has confined its silver hake fishing to Georges Bank, the Gulf of Maine, and southern New England banks (Subarea 5) but the USSR has fished the Nova Scotian Banks (Subarea 4) as well. The species does not occur in commercial quantities north of this Subarea.

TABLE 4

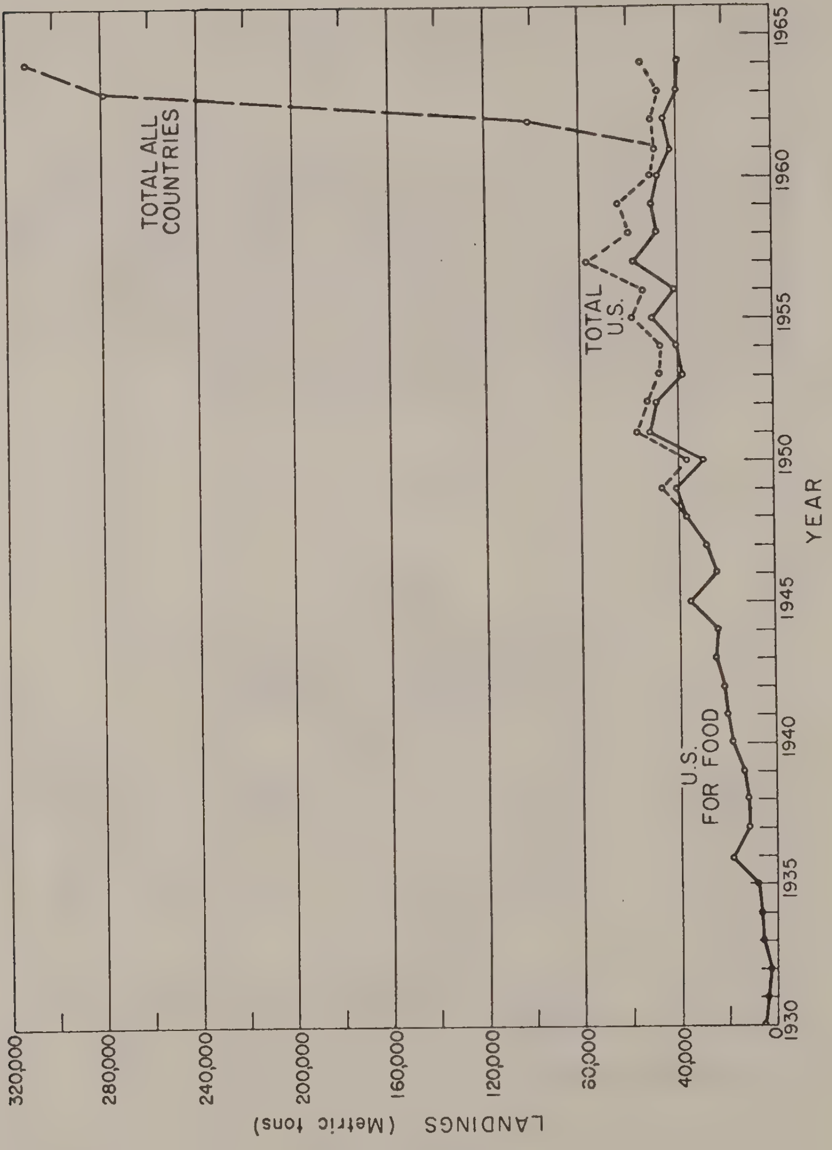
SILVER HAKE STATISTICS, ICNAF CONVENTION AREA
(Thousands of Metric Tons, Live Weight) [1]

Locality of fishing	Landings				Estimated sustainable yield
	High year	Low year	Average 1952-1964	1964	
Subarea 4					
All countries	123.0 (1963)	–	18.6	81.1	100?
U.S.	0	0	0	0	–
Subarea 5					
All countries	220.4 (1964)	45.8 (1961)	82.5	220.4	200?
U.S.	78.7 (1957)	45.8 (1961)	58.1	53.1	–

[1] Includes industrial landings.

Figure 4

SILVER HAKE LANDINGS FROM ICNAF CONVENTION AREA



Herring

Herring is taken in large quantities by Canada, the USSR, and the United States (Figure 5 and Table 5). Canada and the United States fish primarily the inshore stocks of immature fish for canning as sardines but the USSR fishes offshore stocks of mature fish. USSR fishing started in 1962. We do not have adequate information for estimating long-term sustainable yields, but there are indications that the high landings in 1962 and subsequent years are near the maximum sustainable yield.

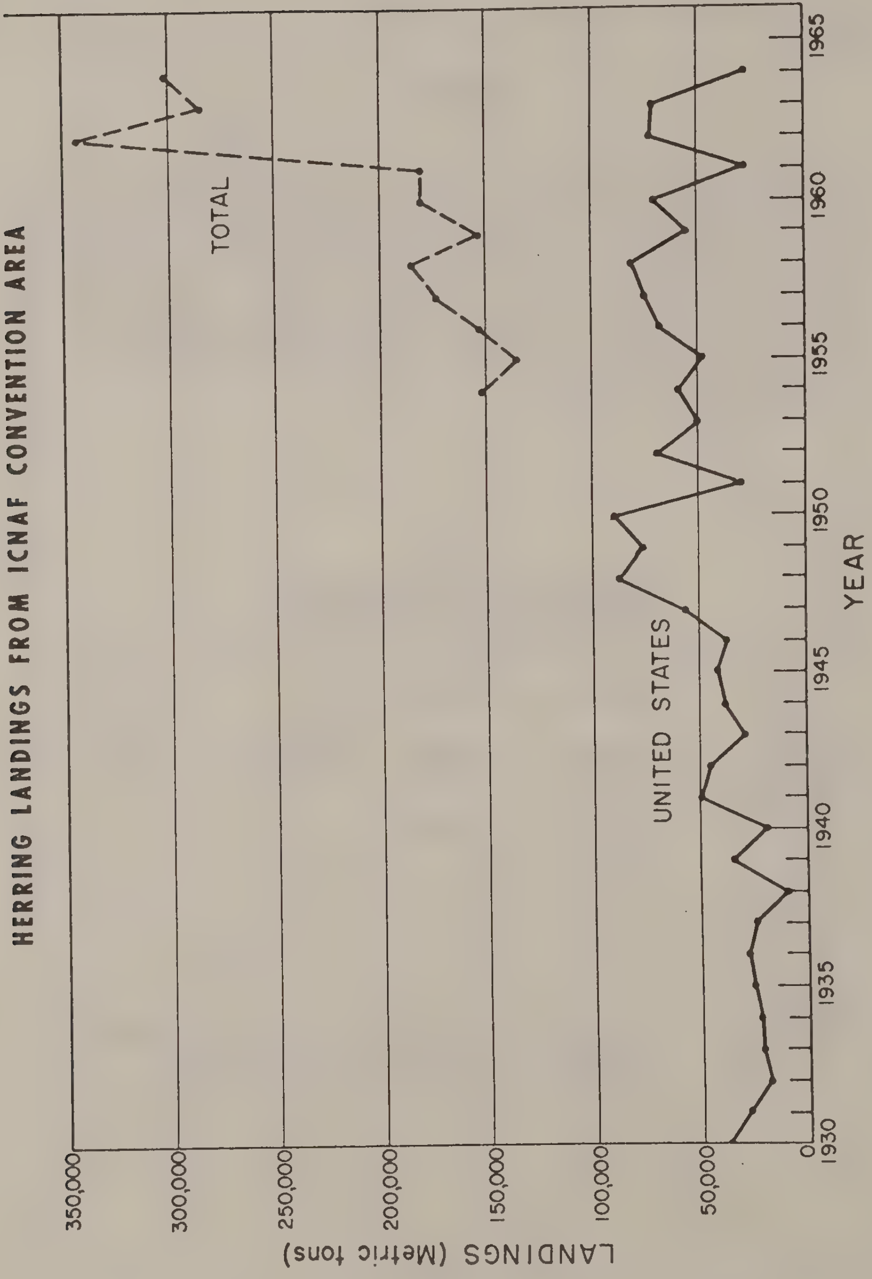
TABLE 5

HERRING STATISTICS, ICNAF CONVENTION AREA
(Thousands of Metric Tons, Live Weight)

Locality of fishing	Landings				Estimated sustainable yield
	High year	Low year	Average 1952-1964	1964	
Subarea 3					
All countries	10.8 (1958)	3.3 (1964)	5.8	3.3	10?
U.S.	0	0	0	0	–
Subarea 4					
All countries	139.5 (1964)	77.9 (1956)	97.8	139.5	100-150?
U.S.	0	0	0	0	–
Subarea 5					
All countries	223.3 (1962)	47.6 (1959)	92.6	159.4	120-200?
U.S.	71.8 (1962)	28.0 (1964)	58.3	28.0	–

Figure 5

HERRING LANDINGS FROM ICNAF CONVENTION AREA



Redfish (Ocean Perch)

The U.S. redfish fishery was developed in the 1930's and reached a peak in 1951, after which it declined (Figure 6). Canadian and European exploitation, started in the 1950's, resulted in a tremendous increase of production for a few years but the catch now appears to be stabilizing at a lower level. Economic factors rather than abundance appear to be limiting the catch at the present time as the estimated maximum sustainable yields for all subareas are higher than the yields being obtained at present levels of exploitation (Table 6).

TABLE 6

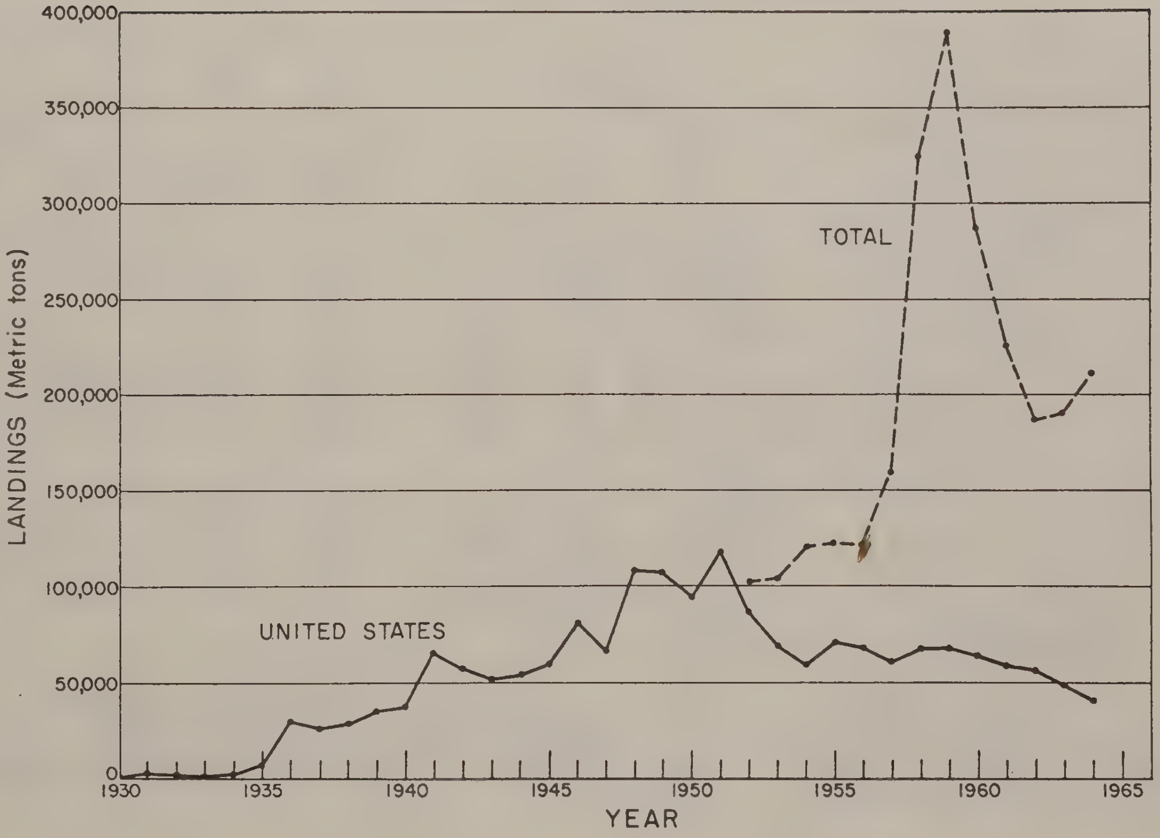
REDFISH STATISTICS, ICNAF CONVENTION AREA
(Thousands of Metric Tons, Live Weight)

Locality of fishing	Landings High year	 Low year	 Average 1952-1964	 1964	Estimated sustainable yield
Subarea 3					
All countries	246.1 (1959)	17.6 (1955)	80.0	94.6	75-150?
U.S. (all from 3 NOP (So. Grand Banks)	33.1 (1953)	4.7 (1959)	16.7	4.7	–
Subarea 4					
All countries	76.7 (1949)	28.6 (1953)	49.2	52.6	65-70
U.S.	76.7 (1949)	19.6 (1953)	33.3	27.9	–
4RST (Gulf of St. Lawrence)					
All countries	49.8 (1955)	6.6 (1962)	24.2	29.8	(25?)[1]
U.S.	34.6 (1955)	0 (1962)	10.4	12.2	–
4VWX (Nova Scotian Banks)					
All countries	76.7 (1949)	9.7 (1955)	23.9	22.8	(45?)
U.S.	76.7 (1949)	9.4 (1955)	20.3	15.7	–
Subarea 5					
All countries	59.8 (1941)	8.3 (1964)	14.4	8.3	15-20?
U.S.	59.8 (1941)	7.8 (1964)	14.0	7.8	–

[1] Values in parentheses not additive.

Figure 6

REDFISH LANDINGS FROM ICNAF CONVENTION AREA



Flounders

The flounder of greatest interest to the United States is the yellowtail (Figure 7). Annual fluctuations in landings result primarily from fluctuations in abundance due to varying recruitment. The value of 25,000 metric tons for the estimated average annual yield in Subarea 5 is less than the amount landed in 1964 (Table 7). This value does not mean the stock is being overfished. Landings have been high in recent years due to unusually good recruitment.

Flounders other than yellowtail are taken in some quantity in all subareas (Table 8), but we have no basis for making estimates of yield for these species.

TABLE 7

YELLOWTAIL FLOUNDER STATISTICS, ICNAF CONVENTION AREA
(Thousands of Metric Tons, Live Weight)

Locality of fishing	Landings				Estimated sustainable yield
	High year	Low year	Average 1952-1964	1964	
Subarea 4					
All countries	5.4 (1964)	0.0 (1956)	1.8	5.4	10?
U.S.	0	0	0	0	–
Subarea 5					
All countries	36.6 (1964)	5.2 (1954)	15.6	36.6	25
U.S.	36.3 (1964)	5.2 (1954)	15.1	36.3	–

Figure 7

YELLOWTAIL LANDINGS FROM ICNAF CONVENTION AREA

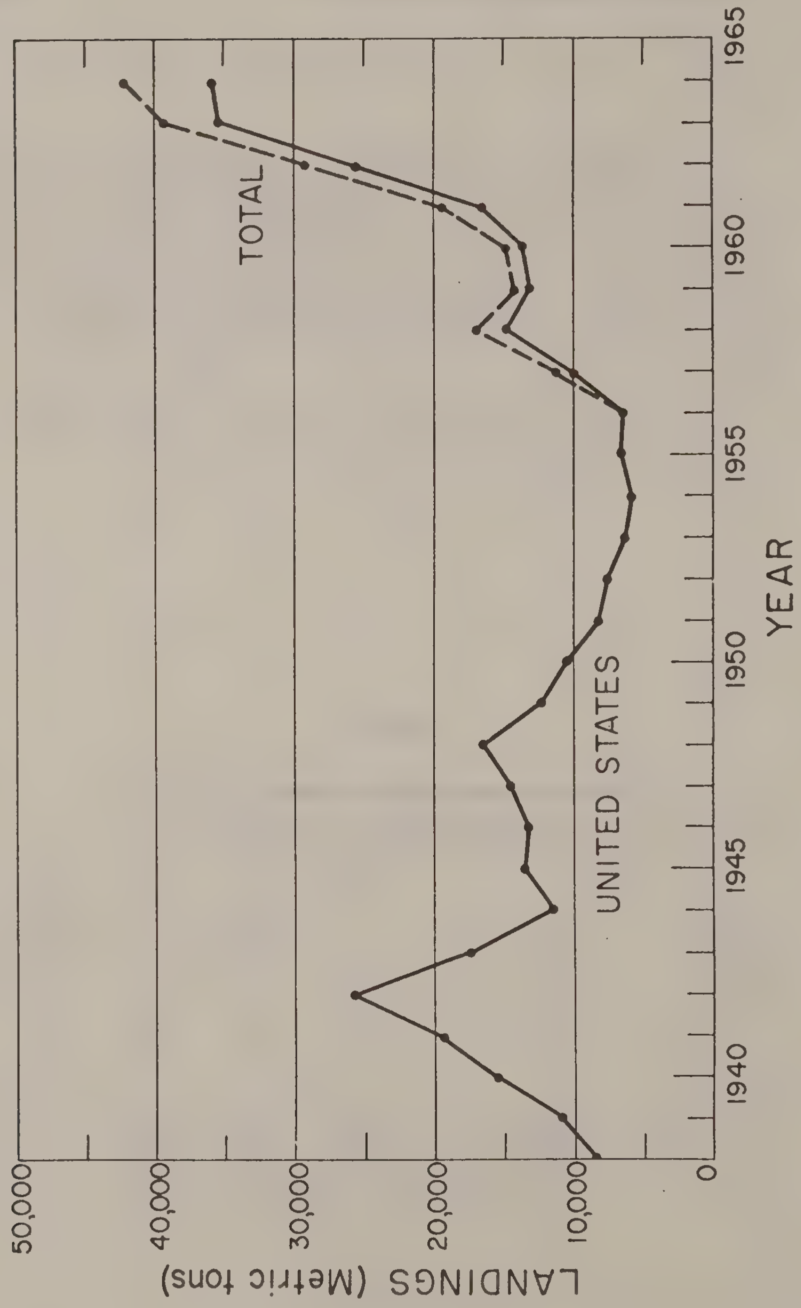


TABLE 8

STATISTICS FOR FLOUNDER, OTHER THAN YELLOWTAIL, ICNAF CONVENTION AREA
(Thousands of Metric Tons, Live Weight)

Locality of fishing	Landings				Estimated
	High year	Low year	Average 1952-1964	1964	sustainable yield [1]
Subarea 3					
All countries	48.5 (1964)	11.4 (1954)	26.9	48.5	?
U.S.	0	0	0	0	–
Subarea 4					
All countries	33.4 (1963)	15.2 (1957)	21.7	28.4	?
U.S.	3.2 (1954)	0.2 (1960)	0.8	0.2	–
Subarea 5					
All countries	20.9 (1964)	11.1 (1958)	12.2	20.9	?
U.S.	20.8 (1950)	9.7 (1962)	11.5	16.8	–

[1] Probably not fully exploited.

Haddock

Haddock landings from the Convention Area have fluctuated widely due to effects of fluctuations in recruitment on the abundance (Figure 8). These wide changes are particularly common in the Grand Bank area, which is the northern limit of the haddock's geographic range and where a good year class occurs only occasionally. United States landings, primarily from Georges Bank (Subarea 5) and Browns Bank (southern part of Subarea 4), have been generally lower in the last few years than previously.

The Georges Bank haddock stock has been studied intensively for many years so that the estimates of maximum sustainable yield are probably better documented than those for any other ICNAF stock. It should be noted that the estimated maximum value of 50,000 metric tons has been exceeded during the past few years (Table 9). Landings from Subarea 4 are also now near the maximum sustainable yield; landings from Subarea 3 have been low recently due to poor recruitment.

Figure 8

HADDOCK LANDINGS FROM ICNAF CONVENTION AREA

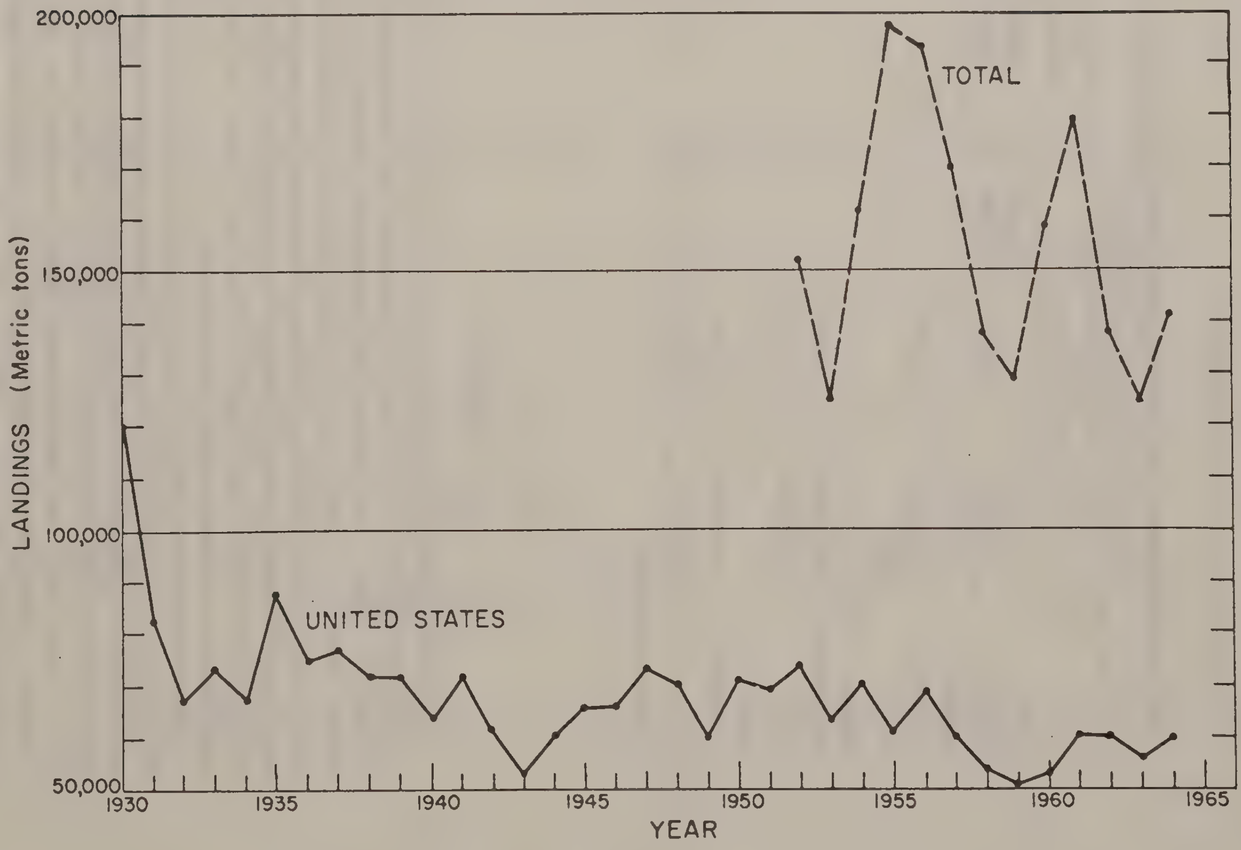


TABLE 9

HADDOCK STATISTICS, ICNAF CONVENTION AREA
(Thousands of Metric Tons, Live Weight)

Locality of fishing	Landings				Estimated
	High year	Low year	Average 1952-1964	1964	sustainable yield
Subarea 3					
All countries	104.5 (1955)	12.4 (1964)	48.1	12.4	50.0
U.S.	0	0	0	0	–
Subarea 4					
All countries	60.0 (1964)	43.1 (1955)	49.3	60.0	60.0
U.S.	50.0 (1935)	6.4 (1962)	12.4	8.4	–
4X (Browns Bank)					
All countries	36.0 (1964)	7.9 (1953)	19.7	36.0	(20.0)[1]
U.S.	15.0 (1931)	5.4 (1959)	8.3	8.5	–
4VW (Eastern Nova Scotian Banks)					
All countries	34.9 (1959)	13.0 (1953)	24.6	22.8	(35.0)
U.S.	9.3 (1948)	0.0 (1964)	2.3	0	–
Subarea 5					
All countries	120.0 (1929)	40.7 (1959)	52.5	69.5	50.0
U.S.	120.0 (1929)	40.5 (1959)	49.6	51.9	–

[1] Values in parentheses not additive.

Sea Scallops

The sea scallop fishery has expanded rapidly since the 1930's (Figure 9). An unusually large year class recruited in 1959 supported the fishery for several years. The expansion of the Canadian fleet of scallop vessels at that time raised the total ICNAF landings well above that of the United States from that year on. Most of the sea scallops come from Subarea 5 (Table 10). Recruitment of scallops is so highly variable that fluctuations in landings can be expected under conditions of heavy fishing pressure but the long-term maximum sustainable yield is probably about 100,000 metric tons live weight (12,000 metric tons of meats) for Georges Bank and 5,000 metric tons live weight (600 metric tons of meat) for Subarea 4.

Figure 9

SCALLOP LANDINGS FROM ICNAF CONVENTION AREA

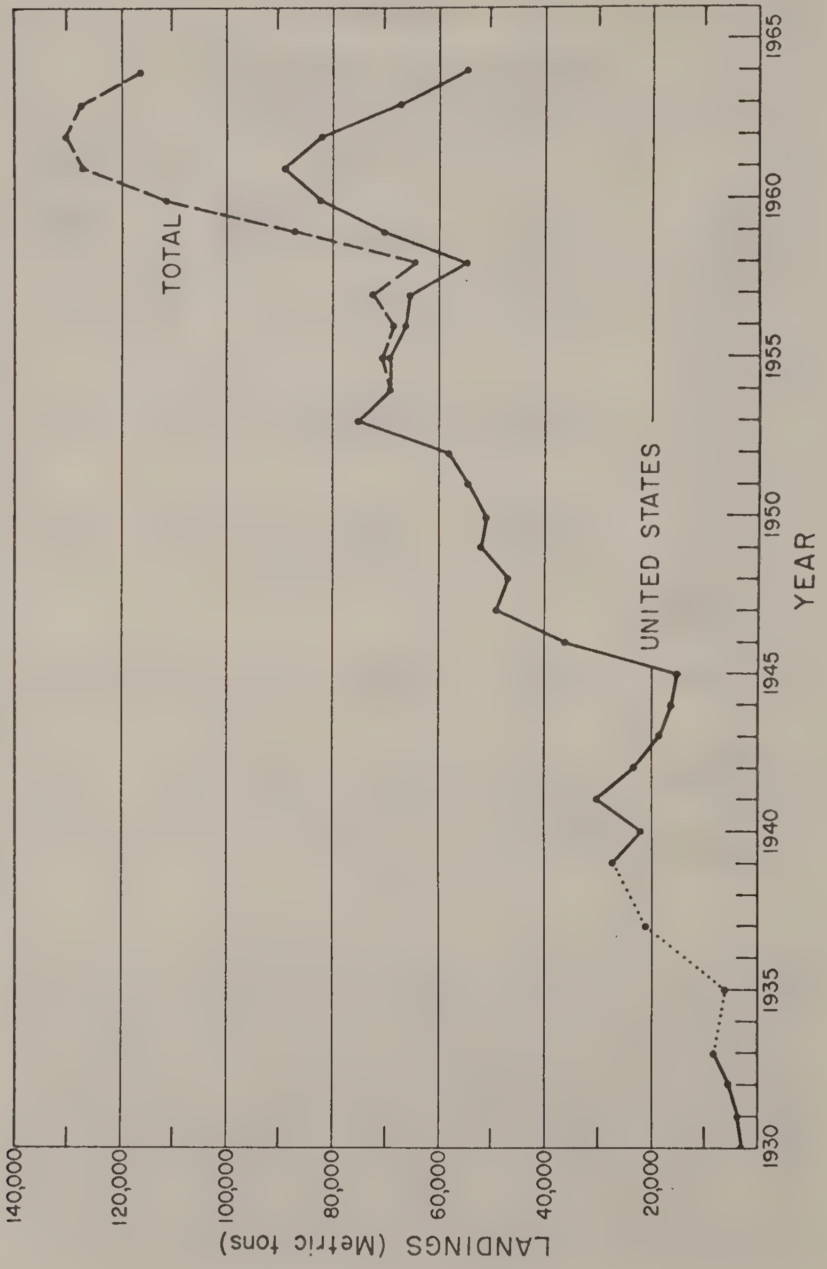


TABLE 10

SEA SCALLOP STATISTICS, ICNAF CONVENTION AREA
(Thousands of Metric Tons, Live Weight)
(Meat Weights in Parentheses)

Locality of fishing	Landings				Estimated sustainable yield
	High year	Low year	Average 1952-1964	1964	
Subarea 4					
All countries	11.5 (1963)	1.6 (1960)	5.4	10.7	5?
	(1.4)	(0.2)	(0.7)	(1.3)	(0.6)[1]
U.S.	0	0	0	0	–
Subarea 5					
All countries	129.0 (1962)	61.5 (1955)	92.5	103.2	100
	(15.5)	(7.4)	(11.1)	(12.4)	(12)
U.S.	89.8 (1961)	44.8 (1958)	64.4	54.1)	–
	(10.8)	(5.4)	(7.7)	(6.5)	

[1] Values in parentheses not additive.

Red Hake

Red hake occurs in commercial concentrations only in the southern part of the Convention Area and was taken only by the United States until 1963, when the USSR started fishing it (Figure 10). Most of the red hake landed by the United States is landed for industrial purposes; a small quantity is for food (Table 11). This species is fairly abundant in the southern part of the Convention Area and is at present underexploited. The long-term maximum sustainable yield is estimated to be 100,000 metric tons.

Figure 10

RED HAKE LANDINGS FROM ICNAF CONVENTION AREA 1948-1964

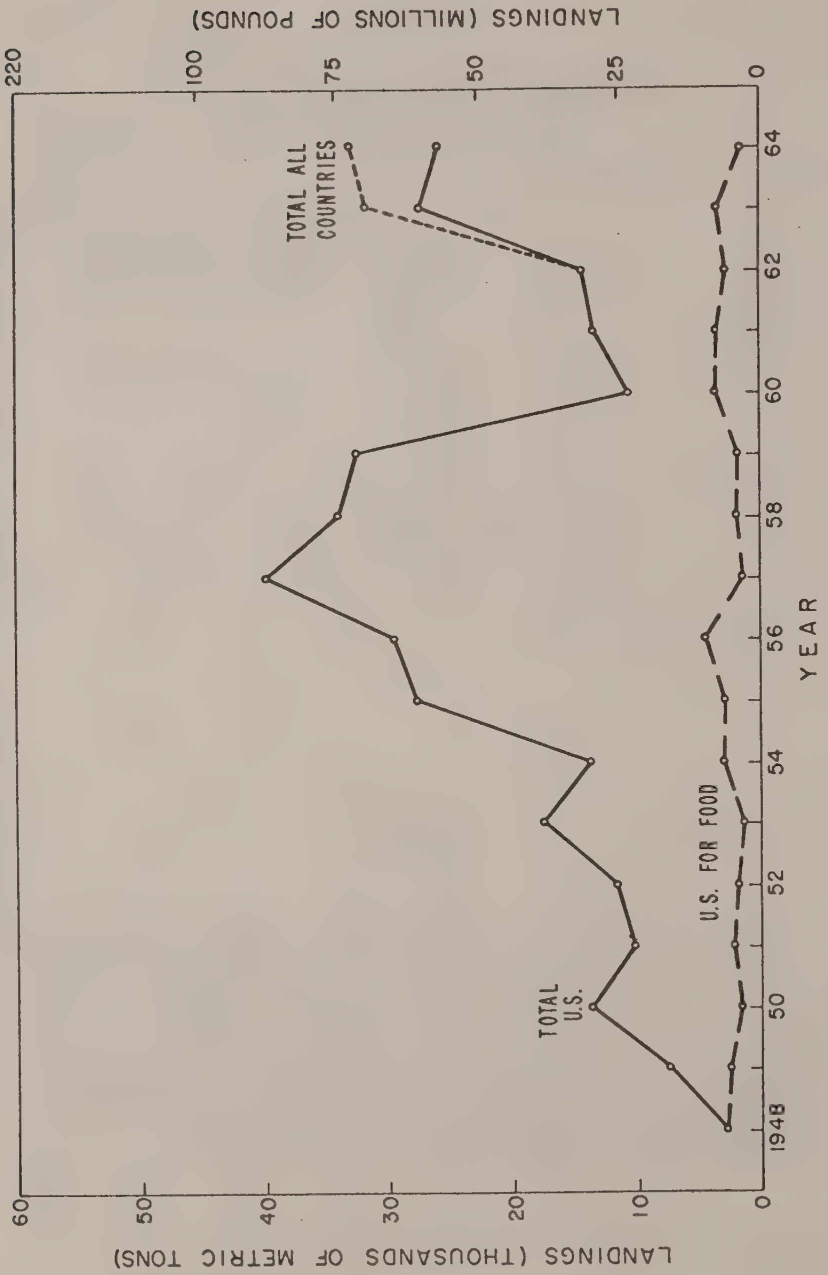


TABLE 11

RED HAKE STATISTICS, ICNAF CONVENTION AREA
(Thousands of Metric Tons, Live Weight)[1]

Locality of fishing	Landings				Estimated sustainable yield
	High year	Low year	Average 1952-1964	1964	
Subarea 5					
All countries	38.7 (1957)	8.6 (1960)	30.0	28.2	100
U.S.	38.7 (1957)	8.6 (1960)	29.4	24.6	–

[1] Includes industrial landings.

Industrial Fishery

Landings of fish from the Convention Area by the United States for reduction to meal and oil and for animal food have varied with market demand, reaching high levels in 1956-59 and dropping to lower levels thereafter (Figure 11). The fishery has started to respond to recently improved markets by increasing landings for industrial purposes. Red hake, silver hake, and menhaden make up the bulk of the catch, but a number of other groundfish species are also included.

Table 12 gives values for industrial groundfish other than silver hake and red hake. As much as 31,500 metric tons of these species were taken (in 1957) when the industrial groundfish fishery was very active. We have no estimates of sustainable yield for these species.

TABLE 12

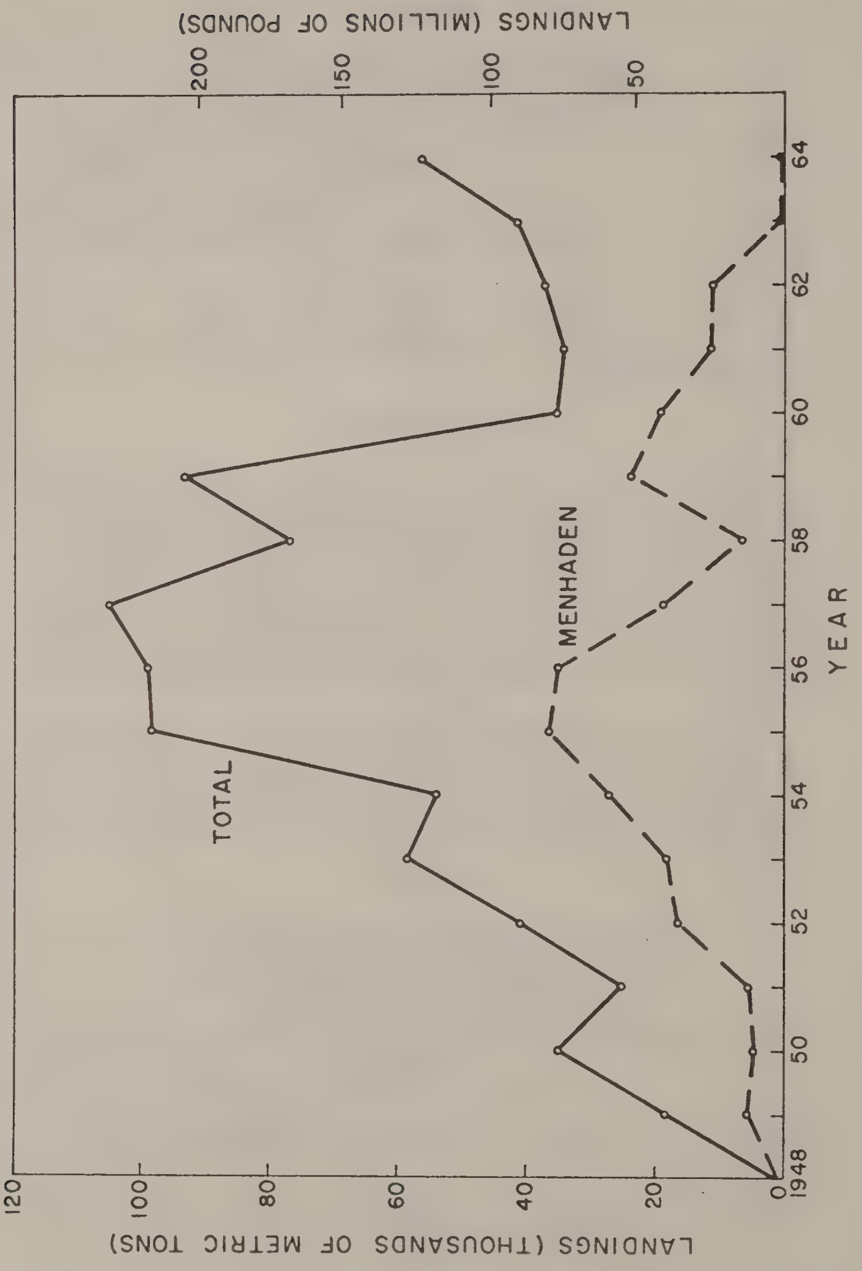
STATISTICS FOR INDUSTRIAL GROUNDFISH, OTHER THAN SILVER HAKE AND RED HAKE, ICNAF CONVENTION AREA
(Thousands of Metric Tons, Live Weight)

Locality of fishing	Landings				Estimated sustainable yield[1]
	High year	Low year	Average 1952-1964	1964	
Subarea 5					
All countries	31.5 (1957)	6.1 (1960)	15.8	7.4	–
U.S.	31.5 (1957)	5.7 (1964)	13.1	5.7	–

[1] Probably not fully exploited.

Figure 11

U.S. INDUSTRIAL FISH LANDINGS FROM ICNAF AREA 1948-1964



Other Species

A number of other species are taken in the Convention Area. Statistics concerning them are given in Table 13, but sustainable yields cannot be estimated for these species at this time. Some species may show considerable increases in future years but there is no reason to believe that any of them occur in great quantities.

TABLE 13

STATISTICS FOR OTHER SPECIES, ICNAF CONVENTION AREA
(Thousands of Metric Tons, Live Weight)

Locality of fishing	Landings				Estimated sustainable yield
	High year	Low year	Average 1952-1964	1964	
Pollock					
Subarea 3					
All countries	7.0 (1954)	1.6 (1964)	4.4	1.6	?
U.S.	0	0	0	0	–
Subarea 4					
All countries	33.0 (1962)	2.3 (1954)	23.7	32.3	?
U.S.	3.1 (1959)	1.0 (1957)	1.9	1.2	–
Subarea 5					
All countries	13.6 (1958)	6.1 (1963)	8.9	9.0	?
U.S.	12.3 (1958)	4.7 (1963)	8.1	4.8	–
Other groundfish [1]					
Subarea 5					
All countries	15.8 (1963)	12.4 (1961)	13.7	12.4	?
U.S.	11.7 (1964)	5.9 (1961)	7.1	11.7	–
Swordfish					
Subarea 3					
All countries	1.0 (1963)	0	0.3	0.5	?
U.S.	0	0	–	0	–
Subarea 4					
All countries	4.8 (1963)	1.3 (1961)	2.4	3.5	?
U.S.	NIL				
Subarea 5					
All countries	3.8 (1963)	0.3 (1954)	1.3	3.5	?
U.S.	0.9 (1963)	0.0 (1964)	0.4	0	–

[1] Associated with catches of major groundfish species: dogfish, skate, scup, tautog, sea robin, titefish, wolffish, eelpout, white hake, cusk, ling.

TABLE 13 (Continued)

STATISTICS FOR OTHER SPECIES, ICNAF CONVENTION AREA
(Thousands of Metric Tons, Live Weight)

Locality of fishing	Landings				Estimated sustainable yield
	High year	Low year	Average 1952-1964	1964	
Tuna					
Subarea 5					
All countries	3.2 (1962)	0.2 (1956)	1.2	1.2	?
U.S.	3.2 (1962)	0.2 (1956)	1.1	0.8	?
Other pelagic fish—mackerel, butterfish, etc.					
Subarea 3					
All countries	1.3 (1955)	0.0 (1960)	0.5	0.8	?
U.S.	0	0	0	0	–
Subarea 4					
All countries	11.8 (1954)	4.2 (1959)	7.8	10.3	?
U.S.	0	0	0	0	–
Subarea 5					
All countries	7.8 (1963)	2.0 (1961)	3.8	3.1	?
U.S.	4.6 (1958)	1.6 (1961)	3.1	2.2	–
Other miscellaneous fin fish					
Subarea 3					
All countries	14.4 (1955)	5.1 (1961)	9.3	13.7	?
U.S.	0	0	0	0	–
Subarea 4					
All countries	17.2 (1964)	5.9 (1961)	10.6	17.2	?
U.S.	0	0	0	0	–
Subarea 5					
All countries	27.1 (1964)	2.4 (1958)	8.7	27.1	?
U.S.	11.9 (1957)	2.4 (1958)	6.8	6.8	–

Conclusion

Although all the world oceans are theoretically available to New England fishermen, the resource base considered here is taken to be the continental shelf between Rhode Island and Greenland, the area which comes under the jurisdiction of the International Commission for the Northwest Atlantic Fisheries. More specifically, it is that part of the Convention Area which has traditionally been fished by New England vessels (excluding New England whalers), namely, the shelf between Rhode Island and the Grand Bank of Newfoundland.

Increased fishing effort by European countries has increased production from the Convention Area but the U.S. catches have held steady or declined. Some stocks of fish in the Convention Area are fished to capacity and increased exploitation of other stocks is not expected to increase total production more than 20 percent; most of these species are not now highly prized.

New England can increase its landings from the Convention Area by the simple expedient of increasing its fishing effort. This is the method of her foreign competitors. The fish are there but they are taken by Canada and countries distant from the fishing banks. The stocks of valuable species of fish have shown an encouraging stability over the years in spite of the very intensive fishing. Whether or not we have reached the peak of production of these species, the only way we can increase our share is to fish more. The economic problems which have prevented the expansion of the New England fleet must be solved so that the U.S. can send modern efficient vessels to the banks capable of outfishing foreign competitors.

Ocean Currents

● Joseph J. Graham, U. S. Bureau of Commercial Fisheries Biological
Laboratory, Boothbay Harbor, Maine

The author presents a good review of the ocean currents and provides some selected lecture-demonstration suggestions for secondary school instruction in biological oceanography.

Introduction

Everything is on the move; nothing stands completely still in, on, or above our earth. Movement is very evident in our daily lives; day changes to night as the earth spins, the clouds go by as the winds blow, and an ocean navigator continually changes course to adjust for currents during a sea voyage. The concept of continual movement is the important point that you should convey to your students. This paper provides a preliminary working knowledge of major forces creating non-tidal currents in the oceans.

Ocean currents are one of the more important environmental factors contributing to our existence. They influence the availability and abundance of our commercial fishes and alter our climates. Many commercial fish produce pelagic (floating) eggs which are transported by currents for some distance. Other fishes attach their eggs to the bottom or to objects on the bottom. Regardless of how they are deposited, fish eggs and the larvae that hatch from them are subject to transport by ocean currents. If currents change from their normal course, the eggs and larvae may enter an area too cold or too salty for survival, or they may be swept into an environment abundant with competitors and predators.

As you till your garden, the currents till the ocean. The movement of water over the bottom causes turbulence and mixing, redistributing the nutrients or fertilizers upward into sunlit water where plants may utilize them. The shore and coastal shelf influence current direction, and many fishes and shrimps are transported into the estuaries which serve as nursery grounds for immature animals. The survival of these animals is the result of a complex series of environmental events that depend on the currents of the oceans. The movement of currents through the open oceans also causes turbulence and mixing so that nutrients are brought into the realm of sunshine penetrating the surface waters. The strength of currents is not uniform from place to place. In general, areas of strong currents are very productive. Some currents can be compared to streams descending from the mountains onto a plain. Near their source they are narrow and fast; as they move along they become broad, slow

Reprinted from THE AMERICAN BIOLOGY TEACHER, Vol. 29, No. 6, September, 1967

down, and, like an old stream on a plain, they meander.

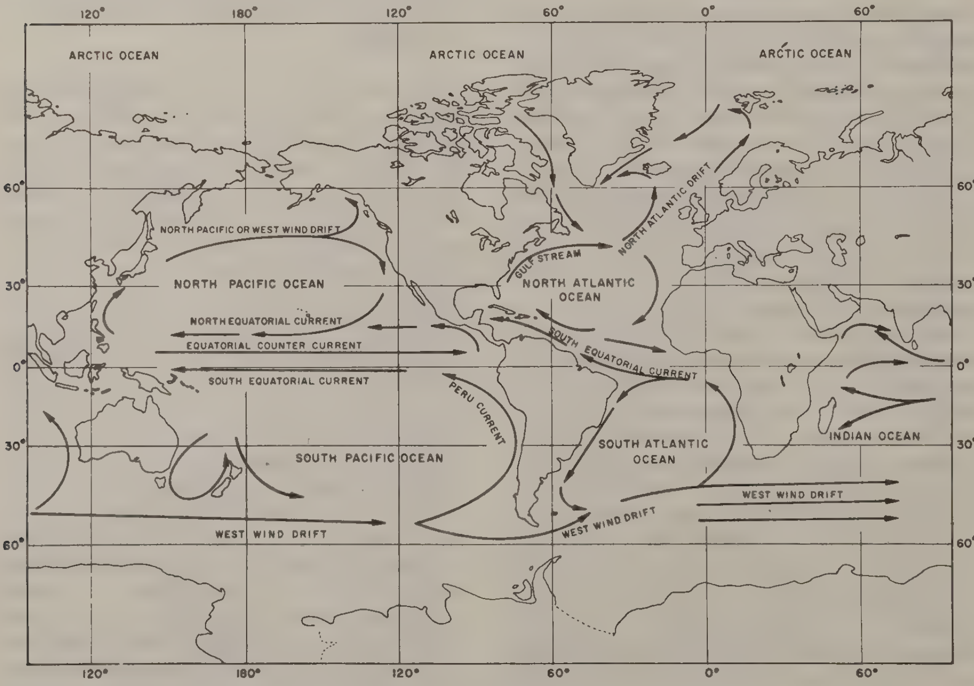
When plotted on world maps the major ocean currents are as conspicuous as mountain ranges on the continents. If interested, you and your students could trace the flow of a particle of water through the oceans, conjecturing where it could go and its effects on the climate of various land masses. For instance, we know that the British Isles are located at about the same latitude as the cold interior of Northern Canada. But the climate of the British Isles is milder than that of the Canadian interior because Britain is bathed by currents that transport some of the warmth from more southern climes (note Gulf Stream and North Atlantic Drift in Fig. 1). Weather that originates over water is generally less extreme and milder than when the source is over land. The seashore and sea breezes are usually preferred to inland heat or cold. Coastal areas frequently have an extended autumn, but summers are generally late. Your physics students will appreciate that this moderation of climate is related partly to the latent heat of water; so that the five-sevenths of the earth's surface which is water can absorb enormous amounts of heat without an increase in temperature, as compared with rock and soil. Of greater importance is the downward distribution and storage of this heat by mixing of the water.

Demonstration

It is intended that the demonstrations described here will provoke thought among your students when they examine the distributions of ocean currents. The demonstrations deal with two fundamental forces creating currents: wind, and water density.

Wind-driven currents

One of the most striking features of our earth is its rotation. This has been particularly evident to us since the beginning of space exploration. This rotation creates a force known as *Coriolis* which guides the flow of our winds and ocean currents. In the northern hemisphere *Coriolis force* deflects wind and water currents to the right or clockwise of their original direction of flow; in the southern hemisphere the de-


120°
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ARCTIC OCEAN
ARCTIC OCEAN
ARCTIC OCEAN
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NORTH PACIFIC OR WEST WIND DRIFT
NORTH ATLANTIC DRIFT
GULF STREAM
30°
NORTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
30°
NORTH EQUATORIAL CURRENT
EQUATORIAL COUNTER CURRENT
SOUTH EQUATORIAL CURRENT
0°
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SOUTH EQUATORIAL CURRENT
PERU CURRENT
30°
SOUTH PACIFIC OCEAN
SOUTH ATLANTIC OCEAN
INDIAN OCEAN
30°
WEST WIND DRIFT
WEST WIND DRIFT
WEST WIND DRIFT
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60°
120°
180°
120°
60°
0°
60°

Fig. 1. Schematic drawing of major ocean currents.

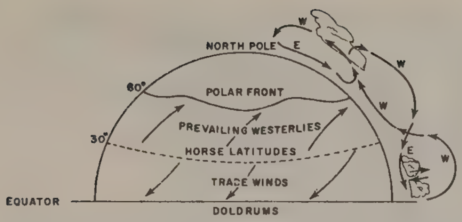

Fig. 2. Wind cells and winds on the rotating earth, northern hemisphere. Adapted from Rossby, U. S. Department of Agriculture, 1941.

flection is to the left or counterclockwise. The force decreases toward the equator.

Fig. 2 shows a scheme for three cells of wind in the northern hemisphere. The trade-wind cell between the Horse Latitudes and the equator has a southward-moving component next to the earth's surface; this component is deflected southwest as the Trade Winds. The polar front cell has a similar component but the resultant wind is highly variable as compared with the Trade Winds. The cell in the middle latitudes has a northward wind component near the earth's surface; it is deflected northeast as the Prevailing Westerlies. Compare these wind directions with the currents in the North Pacific Ocean as follows:

1. Diagram Fig. 2 on the blackboard, including the wind cells and the arrows indicating wind direction.
2. Circulate Fig. 1 among your students, asking them to examine specifically the primary direction of flow in 1) the North Pacific or West Wind Drift Current, and 2) the North Equatorial Current.
3. Note that in the zone of Prevailing Westerlies the *North Pacific Current* flows from west to east, where it is not influenced by land masses (30° - 60°N. Lat., Fig. 2). In the zone of trade winds the *North Equatorial Current* flows in the opposite direction (0° - 30°N. Lat.). Both currents have been deflected slightly to the right or clockwise of the direction of the winds by *Coriolis force*.
4. To summarize the relation between winds, wind-driven currents, and the rotation of the earth, construct on the blackboard the diagram of arrows shown in Fig. 3.

Density-driven currents

Most of your students have seen a weather map in the newspapers or on television and are probably familiar with 1) the low- and high- pressure areas, 2) the lines which follow a given pressure over the map, 3) the differences in spacing between these lines, and 4) the fronts between different types of air masses. A similar map can be constructed for the oceans. Fig. 4 is an example of currents calculated for the coast of Maine. Where the lines are close together the flow of water is faster. Some eddies may be formed. These water currents, like the winds, are related to pressure, and ocean waters move from areas of higher pressure, to areas of lower pressure.

It is sufficient for the purpose at hand to realize that density of water is a prime factor in determining pressure gradients. (For a more detailed explanation of the interrelations of density, salinity, and temperature see Sverdrup *et al.*, 1942, pp. 56-65). Generally, differences in the vertical distribution of density from place to place produce differences in sea-surface height so that water flows downhill relative to a given depth. Density of water is, in turn, controlled by temperature and salinity. The relations between temperature, salinity, and density are shown in Fig. 5, which shows data from an individual oceanographic station. At such a station the temperature (vertical axis) and salinity (horizontal axis) are measured and then plotted on the chart; the depth is indicated in meters (1 meter is

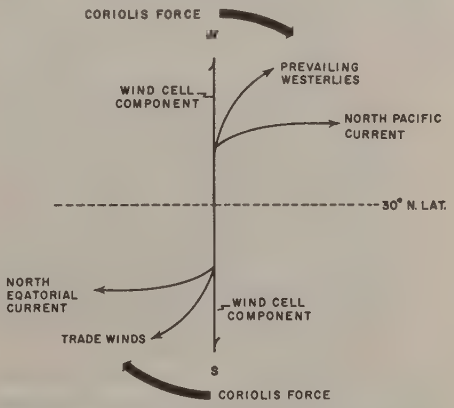

Fig. 3. Schematic drawing of the effect of *Coriolis force* on winds and ocean currents in the northern hemisphere.

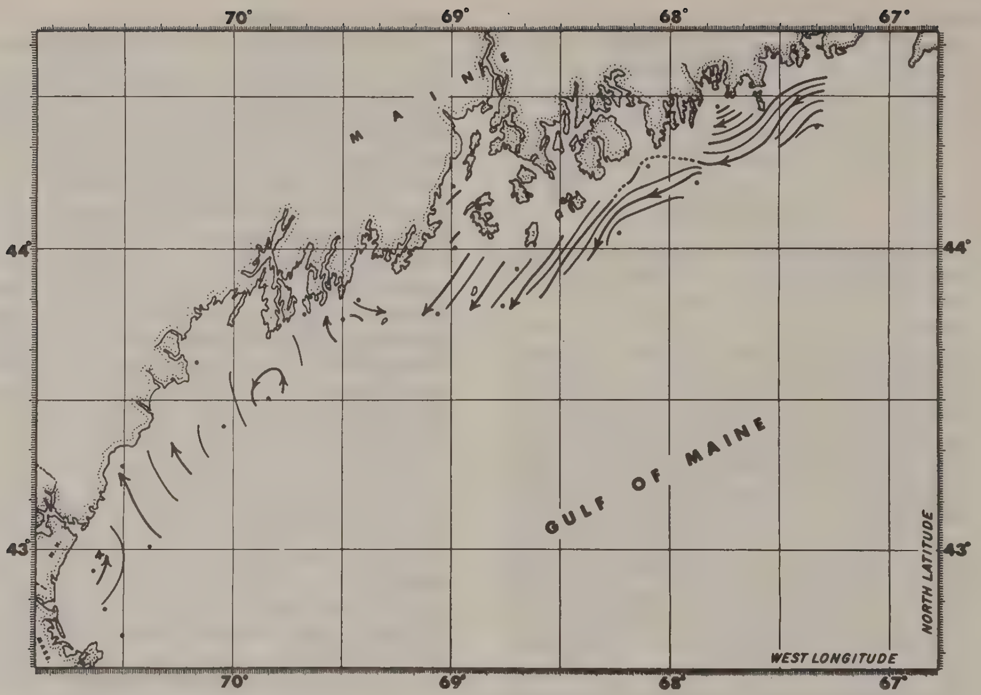

Fig. 4. Relative coastal currents along the Gulf of Maine coast. Arrows indicate direction of flow, closer spacing of lines indicates relatively faster currents.

slightly over 3 feet). A trend line is drawn through the points to suggest the changes from the surface to the bottom. Where the curved density lines pass through the trend line, a corresponding relative density value can be read for the given values of temperature and salinity. Thus, for a bottom temperature of 3°C or 37.7°F and a bottom salinity of 30 o/oo (parts per thousand) the corresponding density (mass per unit volume) is 24.00.

1. Make a similar density determination for the other depths on the graph.
2. On paper with student participation, or on the blackboard, make a plot of the density values obtained (horizontal axis) and the corresponding depth (vertical axis) at which they were measured.
3. Using the chart and the plot of density, indicate the following deductions:
   a. As salinity increases (to reader's right on chart) so does density.
   b. As temperature increases (from top to bottom of chart), density decreases.
   c. From the surface to the bottom of the water column, temperature decreases and salinity increases on your chart and thus density in your plot increases with depth.
   d. Using the data provided in Table 1, have your students determine density values and plot them at their corresponding depths. These examples are from three oceanographic stations in the coastal area of the Gulf of Maine. The curves you obtain differ so that the density of the water from the surface to a given depth, i.e., 30 meters, is less at one station than at another. The sea surface is higher at a station of lower density and water flows "downhill" to stations of higher density. Along a coast, areas near shore are more diluted by stream discharge so that water density is less and sea surface is higher than in offshore areas. In Fig. 4 one would expect the currents to flow offshore in the vicinity of 68° West longitude. But, *Coriolis force* deflects the current

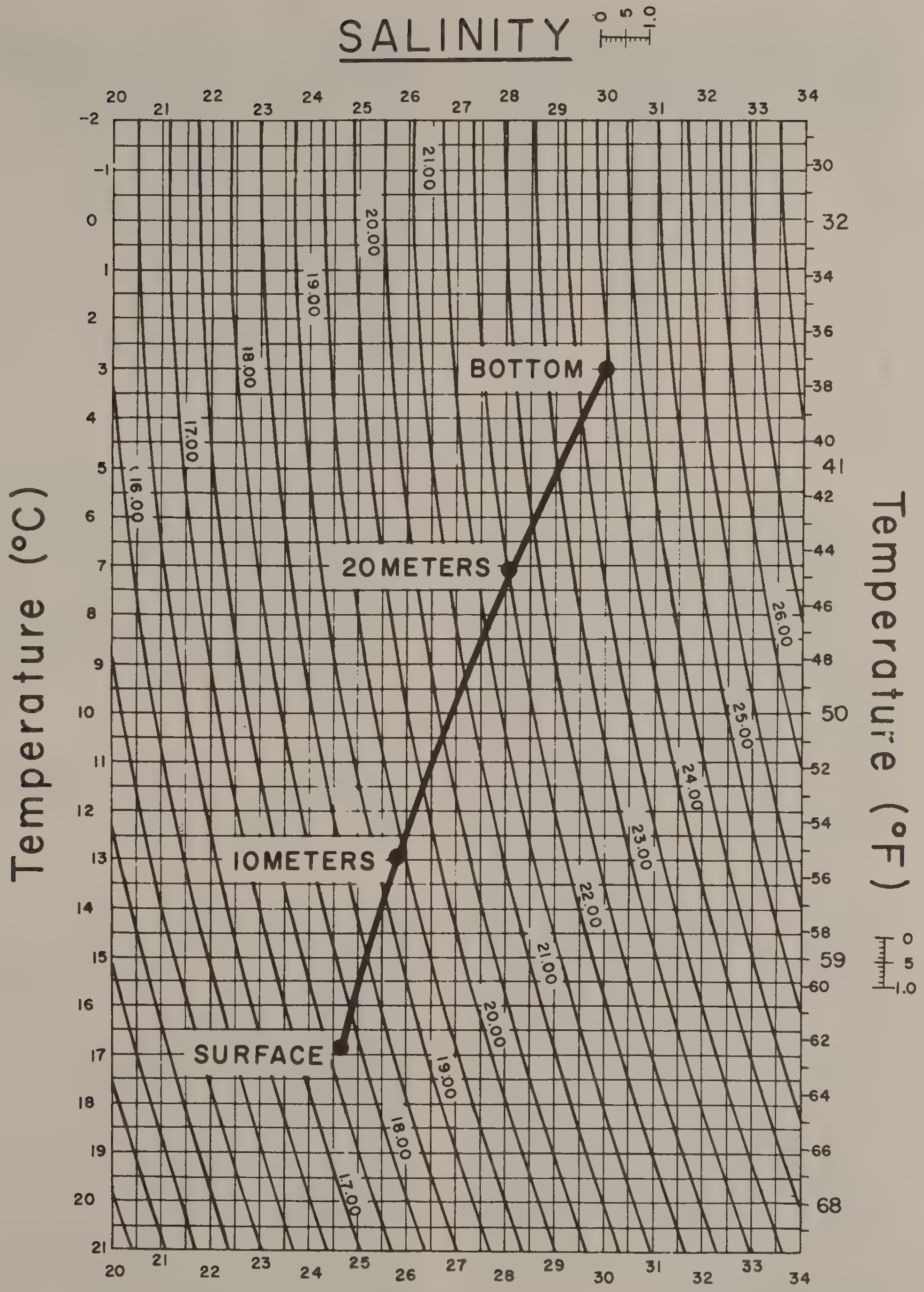

Fig. 5. A data sheet (graph) indicating the relation between density, temperature, and salinity with depth in the ocean.

Table 1.
Some oceanographic observations from the Gulf of Maine

Depth M.	Temp. °C	Salinity 0/00
0	14.5	31.0
10	12.0	31.0
20	7.0	32.0
30	5.5	32.0
82	5.0	32.5
0	13.0	31.0
10	11.0	31.0
20	9.5	31.0
30	8.5	31.5
0	17.0	30.5
10	12.0	31.5
20	9.5	32.0
30	7.5	32.0
92	4.7	32.2

clockwise from the direction it tends to move and an alongshore current is established.

4. To illustrate the role of salinity in water movement (3c and 3d above), divide a rectangular aquarium with a glass or wood partition. In one half, place fresh water; in the other, an equal amount of saturated salt solution containing a common household stain such as ink. Gently remove the partition. Immediately the heavy (dense) salty water will spread out across the bottom, and the lighter, fresh water will replace it at the surface until an equilibrium is reached. The salty water then occurs as a layer along the bottom and the fresh water as a layer along the top, demonstrating the increase of density with depth observed in your students' plots of data. The transitional phase of this experiment also is instructive but it may be difficult to observe in a single experiment if your aquarium is small. If possible, photograph the transitional phase of the experiment, preferably with a Polaroid camera, in the classroom shortly after the partition is removed. The photograph will show that on the side originally containing the salty water is a thinner layer of fresh water overlying a thicker layer of salty water. On the other side is a thicker layer of fresh water at the surface overlying a thinner layer of salty water.

Exhibit material

From a nearby college, university, government, or private laboratory request the following equipment for demonstration:

Nansen bottle—obtains a water sample
Sea-bed drifter—drifts with bottom currents
Drift bottle—drifts with surface currents
Bathythermograph—measures temperature with depth
Current meter—measures directly flow of water

These devices and their operation are described in the listed references.

Expected Results

Points of emphasis

1. Winds and differences in the distribution of density (pressure gradients) are driving forces of the ocean currents.
2. Both winds and currents are altered in their direction of flow by the earth's rotation or *Coriolis force.*
3. The density of the water differs from place to place and these differences are related to changes in temperature and salinity.

Conclusions

In conclusion, the oceans are continually on the move, affecting our climate, transportation, and food supply.

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Encyclopedia Britannica World Atlas. (This volume has an excellent chart of ocean currents.)

Life. The sea. 1961. Time Inc. 190 pp. (Assign this publication as required reading. The coverage of oceanic features is excellent.)

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U. S. Department of Agriculture. Climate and man. 1941. Yearbook of Agriculture. U. S. Government

Printing Office, 1248 pp. (This is an excellent reference in many respects. Review "The scientific basis of modern meteorology" by C. G. Rossby. This section discusses the development of winds in the northern hemisphere.)

Von Arx, W. S. Introduction to physical oceanography. 1962. Addison-Wesley Publishing Company, Inc. 422 pp. (This is a college text and is not recommended for your students. The first chapter on early explorations and ideas is of general interest, however, and scanning of the section on advective processes would prove helpful.)

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Made in United States of America
Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 96, No. 2, 21 April 1967
pp. 126–130

Relationship of the Thermocline to Success of Purse Seining for Tuna

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Relationship of the Thermocline to Success of Purse Seining for Tuna

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ABSTRACT

Bathythermograph casts made with fishing sets on tuna in the eastern tropical Pacific Ocean were examined for a relationship between fishing success and characteristics of the thermocline. Success was highest in thin mixed layers over thermoclines of sharp temperature gradients.

INTRODUCTION

Temperature has been one of the most frequently studied environmental factors affecting behavior and distribution of tuna. To date, much of the work has related regional distribution of tunas to surface temperatures. Laevastu and Rosa (1962) showed general distributions of several tuna species in relation to surface temperatures throughout the world's oceans.

Several studies of the relation of tuna distribution to surface temperature have been made in the eastern Pacific Ocean. Thompson (1917) observed a correlation between sea surface temperatures (using air temperatures as indices) and movements of the albacore (*Thunnus alalunga*) fishery. Clemens (1961) found further evidence of a relation between albacore and temperature. Hester (1961a) developed a method of predicting catches of albacore and bluefin tuna (*Thunnus thynnus*) from coastal sea surface temperatures. A method of forecasting the time albacore will appear has been developed by Johnson (1962); he based predictions on indices of near-surface temperature. Broadhead and Barrett (1964) found a significant correlation between yearly anomalies of yellowfin tuna (*Thunnus albacares*) abundance and yearly anomalies of sea surface temperature at the shore station of Puerto Chicama, Peru.

If temperature limits the horizontal distributions of tunas, then one might expect that it can also limit their vertical distribution. Although no comprehensive studies have been made of relations between tuna availability and characteristics of the thermocline,[1] there has been much speculation, based upon indirect evidence, that such a relationship may exist. Brock (1959) has noted that surface fisheries for tunas seem to be confined to those areas which possess a relatively shallow mixed layer. This condition is a permanent characteristic of the eastern portions of the various oceans, and may occur seasonally elsewhere. Tester (1957), in discussing the relatively high catches of albacore during a POFI (Pacific Oceanic Fishery Investigations) cruise in 1956, suggests the shallow mixed layer as a possible cause, pointing out that the catches decreased following a storm which deepened this layer. In noting the lack of success of purse seining experiments in the Central Pacific, Murphy and Niska (1953) made the observation that tuna consistently sounded out of their net in this area where the top of the thermocline lay deeper than the maximum depth of the net. Sette (1950) conjectured that Atlantic mackerel (*Scomber scombrus*) are kept near the surface of the sea in summertime by a sharp thermocline which exists within 20 fathoms of the surface. With the breakdown of the thermocline in autumn, Sette thought that the mackerel could range deeper.

The temperature gradient within the thermocline of the eastern tropical Pacific typically exceeds 0.2 F/ft (0.4 C/m) and has exceeded 1 F/ft (1.8 C/m) in some of the bathythermograms used in this study. It is not unreasonable to assume that tuna would sense and avoid temperature changes as great as these. Bull (1957) demonstrated that many marine fishes show conditioned responses to temperature changes as small as 0.05 F/ft (0.03 C/m).

If the living space of tunas is indeed restricted vertically by the thickness of the mixed layer and the nature of the thermocline, then

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[1] The layer of relatively sharp temperature gradient separating the mixed layer above from the colder waters beneath.

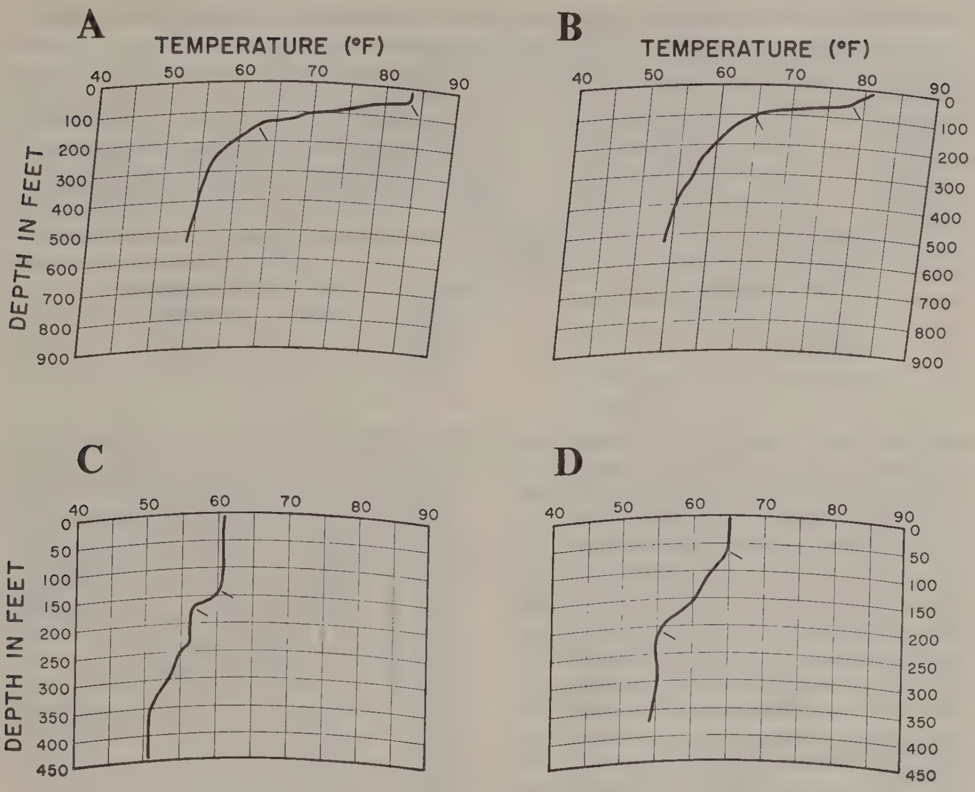

FIGURE 1.—Interpretations of limits of the thermocline from bathythermograms.

variations in these properties should result in measurable differences in the tuna's vulnerability to capture by purse seines, because in the eastern tropical Pacific these nets often but not always extend into the thermocline (Hester, 1961b). Logbook records of tuna fishermen operating in the eastern tropical Pacific show that purse seines capture only about half the number of tuna schools upon which they are set (Schaefer, 1962). These records also show that the percentage of schools set upon that are caught (defined as "rate of success") varies considerably in time and space. The present paper compares rates of success in the eastern tropical Pacific in relation to the thickness of the mixed layer (hereafter termed "depth to the thermocline"), and the average vertical temperature gradient within the thermocline.

FISHING SETS AND BATHYTHERMOGRAPH DATA

Scientists or technicians accompanied purse seiners on regular fishing trips from San Diego and San Pedro, California. These vessels were outfitted with BTs (bathythermographs) and winches permitting BT casts to be made concurrently with fishing sets. Fishermen on several vessels continued to make BT casts on subsequent trips, after our observers had left, for their own information, the Bureau of Commercial Fisheries, and the U. S. Navy. A total of 531 paired observations on thermal structure and fishing sets were thus obtained in the period 1961–64.

Additional data of 1,324 sets were obtained from boats not carrying BT equipment, but fishing in the same areas (within 1° latitude and longitude) and on the same days that BT casts were made. These data were re-

TABLE 1.—*Rates of purse seining success in relation (statistically) to thermocline characteristics*

Depth to thermocline (ft)	Gradient within thermocline (F/ft)								
	<0.30 (0.55 C/m)			≥0.30 (0.55 C/m)			Totals		
	Number of sets	Successful sets		Number of sets	Successful sets		Number of sets	Successful sets	
		Number	Percentage		Number	Percentage		Number	Percentage
≤60 (18.4 m)	425	221	52.0	468	299	63.9	893	520	58.2
>60 (18.4 m)	564	225	39.9	398	182	45.7	962	407	42.3
Totals	989	446	45.1	866	481	55.5	1,855	927	50.0

Analysis of variance based on the arc sin transformations of the percentages and correction for disproportional subclass numbers (Snedecor, 1956, pages 316–320 and 379–382)

Source of variation	d.f.	Mean square	F	Significance
Depth of thermocline	1	33,786	41.15	High <0.01
Gradient within thermocline	1	11,856	14.44	High <0.01
Interaction	1	1,444	1.76	None
Error		821		

covered from unpublished tabulations of fishing effort by area and from fishermen's logbooks (both supplied through the courtesy of the Inter-American Tropical Tuna Commission). The records from logbooks were included to increase the sample size. The basis for their inclusion is that the thermocline properties in most areas of the tropical tuna fishery usually do not change appreciably in one day or over distances of 60 nautical miles (Wyrtki, 1964). The fishing set and BT observations were obtained, in roughly the same proportion as fishing effort, from most of the area fished by the tropical tuna fleet—from Baja California to Peru, and offshore to several hundred miles (Alverson, 1959, 1960, and 1963). The species fished are yellowfin tuna and skipjack tuna (*Euthynnus pelamis*). Sets made with the assistance of aerial spotters, available at a few locations along the coast, were excluded because rate of success increases with aerial assistance (Craig J. Orange, personal communication).

INTERPRETATION OF BATHYTHERMOGRAMS

Upper and lower depths and temperature ranges of the thermocline were read from each bathythermogram. Limits of the thermocline usually were well defined, but subjective decisions were required occasionally. Some of the difficulties in making objective decisions on the depth to the thermocline were discussed by Cromwell (1958). Figure 1 illustrates the method of selecting thermocline limits. In each example, the upper and lower "ticks" indicate the top and bottom of the thermocline. A well defined thermocline, at least at its top is depicted in Figure 1A; 140 ft (42.7 m) was chosen as the bottom of the thermocline because cooling with depth becomes less rapid here than at greater depths. The mixed layer is poorly defined in Figure 1B, but again the depth of the sharper break in slope at 60 ft (18.3 m) was interpreted to be the top of the thermocline, and the gentle break at 100 ft (30.5 m) to be the bottom. Two thermoclines appear in Figure 1C, the more pronounced of which was selected. In Figure 1D, 60 and 200 ft (18.3 and 61.0 m) were chosen as the limits of the thermocline; the variations of the BT trace within those depths appear to be minor.

All purse seine sets were classified according to two properties of the thermocline: its depth and its mean temperature gradient. These two classifications were each subdivided into two subclasses of nearly equal sample sizes.

THERMOCLINE CHARACTERISTICS AND RATE OF SUCCESS

Rates of success of purse seining were clearly related to both depth to the thermocline and temperature gradient within the thermocline (Table 1). Sets where the top of the thermocline did not exceed 60 ft (18.4 m) were more successful (58.2%) than those made where it was deeper (42.3%). Similarly success was greater (55.5%) where the mean temperature gradient within the thermocline was sharpest (over 0.30 F/ft, or 0.55 C/m) than where it was more gradual (45.1%).

Because the interaction mean square is small, we may conclude that the two properties of the thermocline act independently upon rate of success, and that their effects are additive. The additive effect is apparent in Table 1. The combination of large gradient and shallow thermocline gave the highest rate of success (63.9%) and conversely, the combination of small gradient and deep thermocline gave the lowest (39.9%).

The results observed may not have been caused by temperature gradients alone, but temperature may be an index to a combination of ecological factors that act together to produce changes in the availability of tuna. Vertical distribution of disolved oxygen, for example, is closely related to thermal structure in the areas examined, particularly where temperature gradients within the thermocline are large. Typical vertical sections constructed from data taken on EASTROPIC cruises (Bennett, 1963) indicate a mixed layer containing 4 to 6 ml/liter of dissolved oxygen, and a sharp decrease within the thermocline to 1 ml/liter or less just below the thermocline. The lower limit of oxygen concentration required by tuna has not been determined. Studies on other species, however, suggest that low oxygen concentration within and below the thermocline could limit the vertical distribution of tunas.

Another factor that may affect rate of success is the frequent occurrence of a turbid layer within the thermocline (Jerlov, 1958; Ball and La Fond, 1964). It has been suggested that the turbid layer could prevent fish from seeing a net (Hester and Taylor, 1965).

Despite incomplete understanding of the exact effects of the thermocline on tuna, measurements of depth and temperature gradients of the thermocline may be useful in identifying areas where rate of success may be high. They might also improve estimation of tuna abundance from catch-effort data since the latter could be adjusted with respect to these observed differences in availability.

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Ion Fluxes and Short-Circuit Current in Internally Perfused Cells of *Valonia ventricosa*

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ABSTRACT Ion transport in the giant celled marine alga, *Valonia ventricosa*, was studied during internal perfusion and short-circuiting of the vacuole potential. The perfusing and bathing solutions were similar to natural *Valonia* sap and contained the following concentrations of major ions: Na 51, K 618, and Cl 652 mM. The average short-circuit current (I_{sc}) was 97 pEq/cm^2 sec (inward positive current), and the average open-circuit potential difference (PD) was 74 mv (vacuole positive to external solution). Perfused and short-circuited cells showed a small net influx of Na (2.0 pEq/cm^2 sec) and large net influxes of K (80 pEq/cm^2 sec) and Cl (50 pEq/cm^2 sec). Unidirectional K influx was proportional to I_{sc}, but more than one-half of the I_{sc} remained unaccounted for. Both the I_{sc} and PD were partly light-dependent, declining rapidly during the first 1–2 min of darkness. Ouabain (5×10^{-4} M) had little effect on the influx of Na or K and had no effect on I_{sc} or PD. Fluid was absorbed at a rate of about 93 pliter/cm^2 sec. Reversing the direction of fluid movement by adding mannitol to the outside solution had little effect on ion movements. The ionic and electrical properties of normal and perfused cells of *Valonia* are compared.

INTRODUCTION

Since 1891 (30) the marine alga *Valonia* has been a popular organism for studies of electrolyte transport and bioelectrical phenomena. Early work by Osterhout, Blinks, and others on *Valonia* and other giant celled algae produced theories on the nature of protoplasmic surfaces and bioelectrical potentials and a model for membrane transport by means of carrier molecules (8–10, 32, 33). More recent work on *Valonia* has shown that this organism regulates its ionic contents by means of several ion pumps (1, 21, 35). An active extrusion of Na and probably an active uptake of K occur at the plasmalemma, whereas inward active transports of both Na and K take place at the tonoplast (21). An unusual feature of *Valonia* is that the vacuole is electropositive to the

Reprinted from THE JOURNAL OF GENERAL PHYSIOLOGY, Vol. 50, No. 7, pp. 1821–1834, *Printed in U.S.A.*

external seawater (4, 31, 34), due to a large positive potential across the tonoplast (21, 41). *Valonia* also differs from other vacuolated plant cells in the apparent absence of active Cl uptake into the vacuole (21).

Intracellular perfusion recently has become a valuable technique for studying ionic and electrical properties of plant and animal cells. This method was originated by Blinks (6), who perfused the vacuole of the marine alga *Halicystis* by means of fused parallel capillaries. Blount and Levedahl (12) modified Blinks's technique and performed a short-circuit analysis of Na and Cl transport in *Halicystis*. Tazawa and Kishimoto (23, 24, 39) replaced the sap of *Nitella* with artificial solutions by briefly perfusing the vacuole. Internal perfusion of the squid giant axon was accomplished by Baker et al. (2) and Tasaki et al. (38).

Early attempts to perfuse the vacuole of *Valonia* were largely unsuccessful, because the sap contained a small amount of gelatinous material which clogged the perfusion pipets (6). The present paper describes a method for overcoming these difficulties and perfusing the vacuole of *Valonia* with artificial solutions. Fluxes of Na, K, and Cl between external solution and vacuole were measured during partial and complete short-circuiting of the vacuole potential by the method of Ussing and Zerahn (43). Finally, the ionic and electrical properties of perfused and normal cells of *Valonia* are compared.

METHODS

Culture Methods *Valonia ventricosa*, 0.8–1.5 cm diameter, were shipped by air from Puerto Rico. The cells were kept in artificial seawater (Utility Chemical Co., Paterson, N.J.) of about 3.6% salinity to which phosphate, nitrate, and soil extract were added as prescribed by Keck (22). The cells were illuminated 8–12 hr per day at about 2000 lux (natural daylight plus fluorescent lighting), and the temperature was 23°C ± 1°C. *Valonia* were kept under these conditions for several months, but best results were obtained with cells used within 6 wk after arrival.

Perfusion The perfusion and bathing solution was 1 part artificial seawater and 9 parts 0.67 M KCl. The concentrations of major ions (Na 51, K 618, and Cl 652 mM) were similar to those in normal sap of *V. ventricosa* (Na 44, K 625, Cl 643 mM) (21). Most of the other ions in the perfusion solution, however, were not normal constituents of *Valonia* sap (15). The pH of the artificial solution was 7.1–7.4, whereas the pH of normal sap was 6.0–6.4. Cells perfused and bathed in this solution survived longer (up to 4 days) and gave higher potentials than cells perfused and bathed with various other artificial solutions which did not contain a portion of seawater. *Valonia* could not be internally perfused with 100% seawater or other high Na solutions, however, because this caused disjunction of the protoplasm and formation of aplanospores (25).

The perfusion assembly is shown in Fig. 1. A spherical cell about 1 cm diameter was placed in a glass dish on the stage of a dissecting microscope. Waterproof putty held the cell in place until after insertion of the pipets. Pipets were pulled from 1 mm

Pyrex[1] tubing and broken to give sharp beveled tips about 0.1 mm (inflow pipet) and 0.3 mm (outflow pipet) diameter. The pipets were attached to the inflow and outflow reservoirs by 1 mm plastic tubing. The pipets and tubing first were filled and then clamped so that the cell would remain at least partly turgid after the initial puncture. By means of two micromanipulators the outflow pipet, and then the inflow pipet, were forced through the cell wall (8–13 μ thick) and underlying protoplasm (8–10 μ thick) (19) into the vacuole or sap cavity. The large outflow pipet irreversibly damaged about 20% of the cells, but smaller pipets often became clogged with the gelantinous material in the sap.

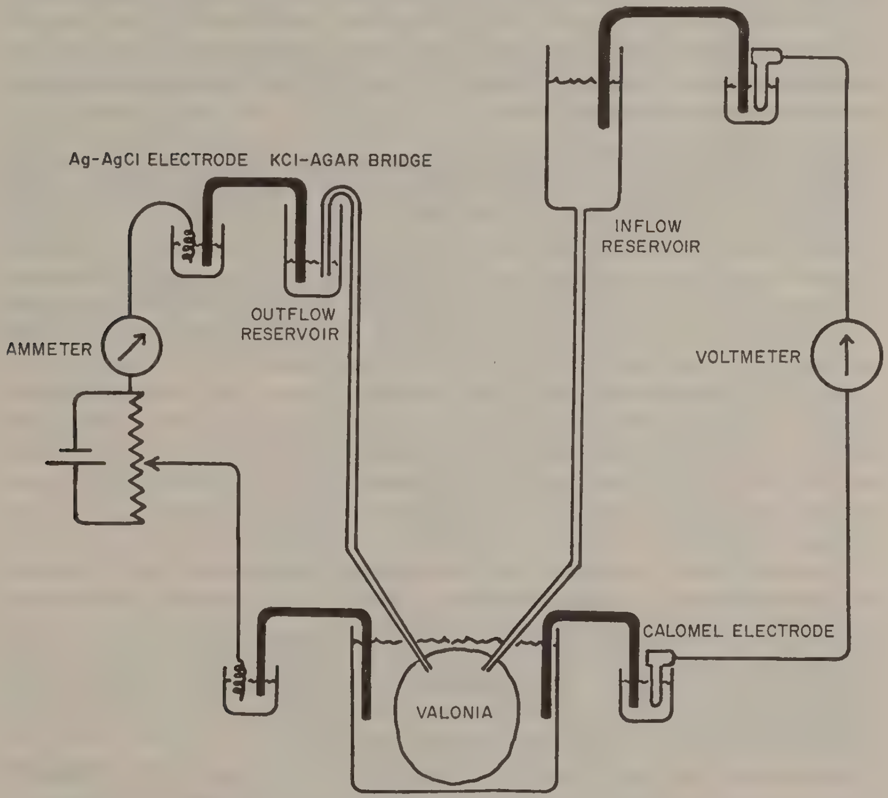

Figure 1. Assembly for internal perfusion and electrical measurements in single cells of *Valonia ventricosa*. Not shown are the micromanipulators holding the inflow and outflow pipets and the dissecting microscope supporting the cell chamber.

Perfusion was started after the cytoplasm had formed an electrically resistant seal around the pipets, as indicated by a gradual rise in the vacuole potential from near zero to 20–50 mv. Gentle suction was applied frequently to the outflow tube until the vacuole was cleared of gelatinous material. Perfusion then was maintained by gravity with the inflow reservoir 30–50 cm above the cell chamber and 10–20 cm above the the outflow reservoir. The resulting hydrostatic pressure was only a small fraction of the normal turgor pressure in *Valonia* (about 2 atmospheres). To check the extent of mixing in the vacuole a small amount of methylene blue was sometimes added to the inflow reservoir. The turnover time for vacuolar contents was 10–20 min, depending on the cell volume and flow rate. Ion flux measurements began about 4 hr after the initial puncture. Cells were illuminated (about 4000 lux, "daylight" fluorescent), and the bath temperature was 24 ± 1°C.

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[1] Trade names referred to in this publication do not imply endorsement.

Electrical Measurements The electrical circuits are shown in Fig. 1. The potential difference (PD) between vacuole and bathing solution was measured with a high impedance voltmeter (Keithley model 600A (Keithley Instruments, Cleveland, Ohio)). The inflow reservoir and bathing solution were connected to the voltmeter by agar bridges (0.6 M KCl) and calomel electrodes. The shunt circuit consisted of the outflow pipet, KCl-agar bridges, Ag-AgCl electrodes, battery, voltage divider, and microammeter, as prescribed by Ussing and Zerahn (43). The resistances of the potential-measuring circuit and shunt circuit were about 400 and 200 kohm, respectively. The high conductance of the solutions relative to the membrane conductance of *Valonia* permitted the asymmetrical arrangement of the current electrodes. Errors due to flow potentials were also insignificant due to the high conductance of the artificial sap. The normal vacuole potential was short-circuited by applying sufficient current to reduce the PD to zero. This short-circuit current (I_{sc}), as well as the open-circuit PD, was recorded at 5–10 min intervals throughout each experiment.

Occasional leaks around the pipets were detected microscopically and electrically. Any serious leakage across the protoplasm caused a rapid drop in the open-circuit potential to near zero. Furthermore, an undetected leak in short-circuited cells would not cause an appreciable net flux of ions across the protoplasm, because the electrochemical potential gradient for all ions was approximately zero. Finally, an upper limit for the possible leak flux of K and Cl would be equal to the small K efflux observed in perfused and short-circuited cells (Table II).

The PD across the plasmalemma was measured with glass microcapillary electrodes containing 1 M KCl and having tip diameters of 1–3 μ and resistances of 3–16 megohms. The plasmalemma PD was measured in young cells, 5–15 hr old and 100–300 μ in diameter, as described previously (21). These cells were largely protoplasm rather than vacuole, and their thin cell walls offered little resistance to microelectrode penetration. The electrical circuit was identical to the potential-measuring circuit described above.

Ion Flux Measurements Ion fluxes between external solution and vacuole were measured with radioisotopes (^{22}Na, ^{42}K, and ^{36}Cl) and conventional detectors (Baird-Atomic model 510 (Baird-Atomic, Inc., Cambridge, Mass.) and Nuclear Chicago model C-115 (Nuclear-Chicago Corp., Des Plaines, Ill.)). Specific activities of the tracers were high enough to limit the increase in the stable ion concentration to less than 1%.

To estimate the unidirectional influx of an ion, tracer was added to the bathing solution and the rate of appearance of radioactivity in the perfusate was measured. The perfusate was collected at 15–30 min intervals starting 1–2 hr after clamping the vacuole potential at zero and adding tracer to the outside solution. Unidirectional influx was calculated by the equation

$$M_i = \frac{P_i}{tp_o^* A}$$

where M_i is the influx in mole/cm² sec, P_i is the amount of radioactivity in the perfusate collected during the time interval t, p_o^* is the specific activity of the outside solution, and A is the surface area of the spherical cell. Ion efflux was estimated in a similar manner, except that tracer was added to the inflow reservoir and the rate of appearance of radioactivity in the outside solution was measured. This calculation assumes that both the specific activity and total ion content of the cytoplasm were constant during the flux measurements. This assumption seems justified because the rate of tracer flux was fairly constant for five to nine consecutive samples during at least 2–4 hr and sometimes more than 24 hr, whereas the estimated maximum half-times for exchange of cytoplasmic ions ranged from 0.5 to 1.7 hr.

TABLE I

CONCENTRATIONS OF Na, K, AND Cl IN ARTIFICIAL SAP AND IN PROTOPLASM OF *Valonia**

		Protoplasm	
Ion	Artificial sap	Cells bathed in artificial sap	Cells bathed in seawater‡
	*m*M*/liter*	*m*M*/kg water*	*m*M*/kg water*
Na	51±1 (10)	22±3 (10)	40±2 (8)
K	618±1 (10)	571±11 (10)	434±9 (8)
Cl	652±3 (10)	277±13 (10)	138±4 (8)

* Mean, SE, and number of measurements in parentheses.
‡ Data taken from Gutknecht (21).

RESULTS

Ion Concentrations in Protoplasm and Artificial Sap Protoplasm was collected and ion concentrations were measured as described previously (21). Briefly, a large cell was cut in half and washed in cold, isosmotic, Tris-sulfate buffer, pH 7.8. The protoplasm was scraped from the cell wall, collected in a capillary tube, and separated from the buffer by centrifugation. Then the protoplasmic fraction was weighed, recombined with the supernatant buffer, and diluted with 0.1 N HNO_3 to a volume suitable for analysis by flame photometry (Na and K) and coulometric titration (Cl). The samples of protoplasm contained 60–65% chloroplasts (18).

Table I gives the concentrations of Na, K, and Cl in the protoplasm of

Valonia bathed either in sea water or for 4–5 hr in artificial sap. The cells were not internally perfused or short-circuited. The exposure time of 4–5 hr was estimated from the volume of protoplasm and the ion fluxes to be long enough to allow protoplasmic ion concentrations to reach a steady state. Exposure to artificial sap resulted in a decrease in the Na concentration from 40 to 22 mM and an increase in the K concentration from 434 to 571 mM and in the Cl concentration from 138 to 277 mM. The low Na and fairly low Cl concentrations suggest that samples of protoplasm were not highly contaminated with either seawater or sap.

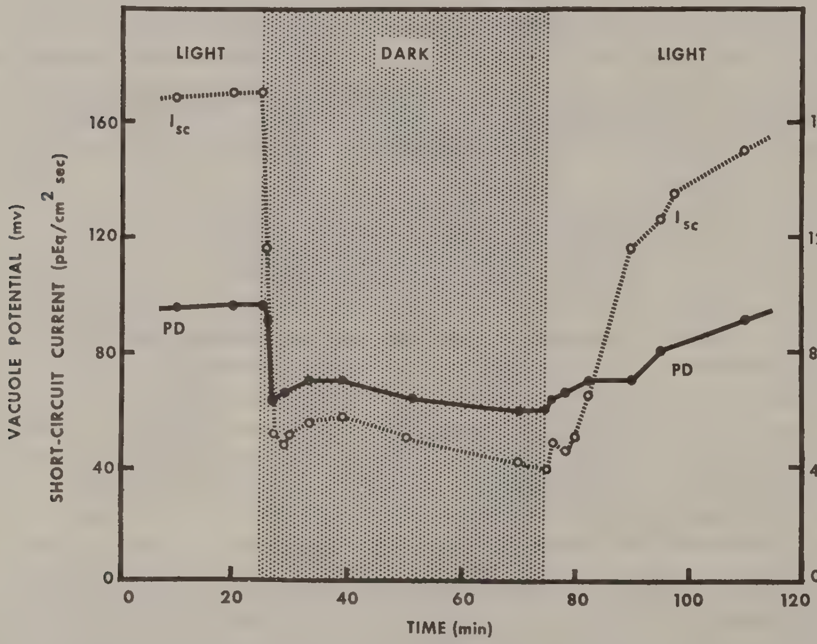

FIGURE 2. Effect of illumination (4000 lux) on short-circuit current (I_{sc}) and open-circuit potential (PD) in an internally perfused cell of *Valonia ventricosa*.

Short-Circuit Current, Potential Difference, and Resistance The short-circuit current (I_{sc}) in perfused *Valonia* was 97 ± 12 pEq/cm² sec (33 cells), or about 9.4 μamp/cm². (Results are expressed in the sequence: mean, SE, and the number of measurements in parentheses.) The open-circuit PD was +74 ± 6 mv (33 cells), vacuole positive to outside solution. Several cells which gave PD's of less than +30 mv were not included in the results. Both the I_{sc} and PD were partly light-dependent, falling rapidly during the first 1–2 min of darkness and rising gradually during subsequent illumination (Fig. 2). The sensitivity of the vacuole potential to light agrees with the early work of Marsh (29) on *V. ventricosa*, but differs from results on other algae; e.g., *Halicystis* (7), *Nitella* (3), and *Gracilaria* (20), in which the vacuole potential was rather insensitive to light. The large PD displayed by *Valonia* immersed in sap was observed first by Osterhout, Damon, and Jacques (16, 34) and demonstrated surprisingly that a thin layer of protoplasm could be electrically asymmetrical.

The plasmalemma PD in young cells bathed in artificial sap for 0.5–6.5 hr was +17.8 ± 0.8 mv (30 cells), cytoplasm positive to external solution. This value differs greatly from the normal plasmalemma PD of −71 mv (21). The plasmalemma PD in perfused *Valonia* could not be measured directly, because the cell wall was as thick as the underlying protoplasm and the cells were not turgid. In perfused but not short-circuited cells the tonoplast PD would be about 56 mv, cytoplasm negative to vacuole, i.e., the difference between the vacuole PD of 74 mv and the plasmalemma PD of 18 mv. In short-circuited cells the cytoplasmic PD is probably between +18 and −56 mv, but the final value will depend on the relative membrane resistances which are not yet known.

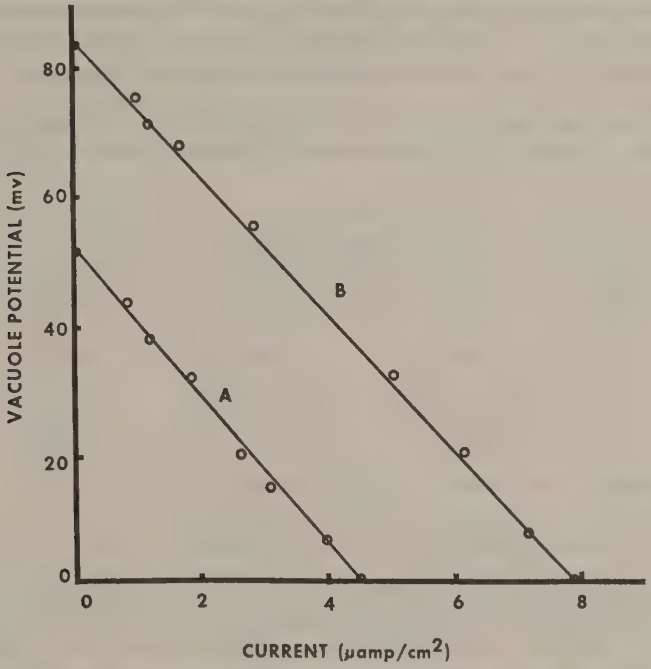

FIGURE 3. Relation between current and voltage in a perfused *Valonia* cell before short-circuiting (A) and after short-circuiting 1–2 hr (B).

The direct current resistance of the protoplasm of *Valonia* perfused and bathed with artificial sap was 9.4 ± 1.4 kohm cm^2 (13 cells). The resistance was estimated from the slope of the current-voltage curve, which was approximately linear over the range shown in Fig. 3. Curve A is the current-voltage relation for a cell perfused but not short-circuited, and curve B is the current-voltage relation for the same cell after short-circuiting for 1–2 hr. The value of 9.4 kohm cm^2 for the resistance of *Valonia* protoplasm agrees with early measurements of Blinks (4) on normal cells of *V. ventricosa*. The resistance of *Valonia* protoplasm is one to two orders of magnitude greater than that of most animal epithelia, about one order of magnitude greater than that of the marine alga *Halicystis* (11), and about one-half the resistance of *Nitella* and *Chara* (44).

Ion Fluxes and Short-Circuit Current Fluxes of Na, K, and Cl across the protoplasm of perfused and short-circuited *Valonia* are shown in Table II. All three ions showed a net influx, i.e., Na 2.0, K 80, and Cl 50 pEq/cm^{2}sec. The unidirectional influxes of Na and K were fairly similar to the influxes in normal cells (21). Na and K effluxes, however, were much smaller in perfused cells than in normal cells. Both influx and efflux of Cl in perfused and short-circuited *Valonia* were several times larger than in normal cells. Unidirectional K influx was proportional to the I_{sc} (Fig. 4). A large part of the I_{sc} was unaccounted for, however, because the net influx of Cl neutralized much of the positive charge carried inward by Na and K (Table II).

TABLE II

FLUXES OF Na, K, AND Cl BETWEEN EXTERNAL SOLUTION AND VACUOLE OF PERFUSED AND SHORT-CIRCUITED *Valonia**

Ion	Influx	Efflux	Net influx
	pEq/cm² sec	*pEq/cm² sec*	*pEq/cm² sec*
Na	2.62±0.39 (3)	0.55±0.16 (3)	2.04±0.42
K	85.2±29.0 (7)	5.20±2.40 (4)	80.0±29.0
Cl	76.7±11.0 (9)	27.2±4.9 (5)	49.5±12.0

* Mean, SE, and number of cells in parentheses.

The effects of a constant +40 mv PD on Na, K, and Cl fluxes are shown in Table III. The fluxes were measured in single cells with the PD clamped first at 0 mv, then at +40 mv, or vice versa. A large net influx of K and small net influx of Na persisted in spite of the adverse electrical potential gradient. Another notable result was the large inhibition of Cl efflux when the vacuole PD was +40 mv.

The effect of ouabain, a specific inhibitor of Na and K transport in many cells, was tested. Influx of Na and K was measured before and after the addition of ouabain (5 × 10^{-4} M) to both the perfusion and bathing solutions. Na and K influxes before the addition of ouabain were 2.8 ± 0.1 (7) and 64.7 ± 2.4 (6) pEq/cm² sec. Na and K influxes after the addition of ouabain were 3.0 ± 0.2 (3) and 52.0 ± 4.7 (7) pEq/cm² sec. The effect of ouabain on K influx may be significant ($p < 0.05$) but is considerably smaller than the effect of this concentration on most other cells, e.g., *Nitella* (26). Cation transport in the marine algae, *Ulva lactuca* and *Chaetomorpha darwinii*, however, is insensitive to ouabain (13, 17). Ouabain had no effect on either I_{sc} or PD in *V. ventricosa*.

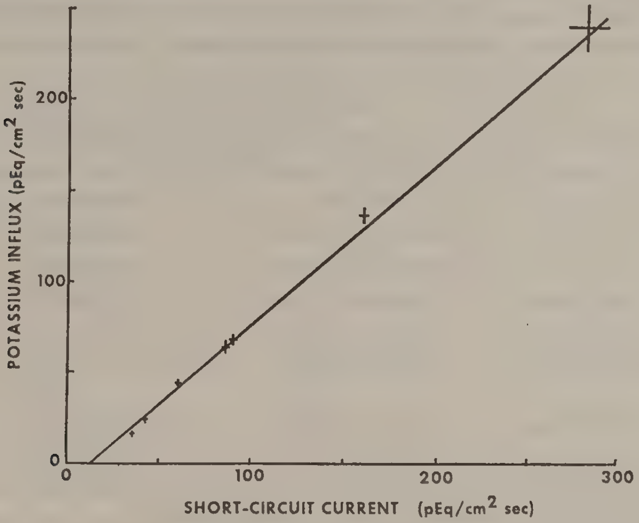

Figure 4. Relation between unidirectional K influx and short-circuit current in internally perfused cells of *Valonia*. Line is least squares regression, $r > 0.99$, $p < 0.01$. Vertical and horizontal bars represent the SE of three to seven measurements made on each cell.

Fluid Absorption Fluid absorption was measured by a calibrated microliter pipet attached to the outflow tube while the inflow tube was closed. The cells had been perfused previously with artificial sap but were neither perfused nor short-circuited during these measurements. Fluid was absorbed at a rate of 93 ± 15 pliter/cm² sec (six cells). If the absorbed fluid was isosmotic to the perfusion and bathing solutions, its salt concentration would be about 0.67 M. The rate of salt absorption, therefore, would be about 62 pM/cm² sec, which is reasonably close to the observed net influxes of K and Cl (Tables II and III).

The possible effect of fluid absorption on ion movements was tested in one experiment. Cl influx was measured before and after reversing the direction of fluid movement by adding mannitol (50 mM/liter) to the outside solution.

The rates of fluid absorption before and after the addition of mannitol were 80 ± 8 (5) and −349 ± 19 (4) pliter/cm^2 sec, respectively. Cl influx decreased only slightly, however, from 131 ± 2 (6) to 125 ± 2 (5) pEq/cm^2 sec after the addition of mannitol to the outside solution. Thus the interaction between ion movements and water movements due to simple osmosis across the protoplasm of *Valonia*, on the basis of this single experiment, appears to be small.

Preliminary data suggest that the hydraulic conductivity of *Valonia* protoplasm is about 10^{-7} cm/sec atm. This value may be combined with the rate of increase in the osmotic pressure in the vacuole due to net salt influx (Tables II and III) to give a predicted rate of fluid influx by simple osmosis. The predicted rate is at least an order of magnitude smaller than the observed rate of about 93×10^{-9} cm/sec. This discrepancy suggests that the transfer of approximately isosmotic fluid across the protoplasm of *Valonia* may involve a coupling between salt and water movements like that in many animal epithelia.

TABLE III

EFFECT OF VOLTAGE CLAMPING AT +40 MV ON FLUXES OF Na, K, AND Cl IN PERFUSED *Valonia**

Ion flux	PD = 0 mv	PD = +40 mv
	pEq/cm² sec	*pEq/cm²sec*
Na influx	2.77±0.11 (7)	1.47±0.12 (3)‡
Na efflux	0.36±0.19 (7)	0.53±0.24 (7)
K influx	63.6±2.0 (10)	54.9±3.6 (8)§
K efflux	1.48±1.96 (13)	2.90±5.69 (8)
Cl influx	66.4±1.2 (5)	67.2±3.9 (4)
	110.8±2.0 (6)	112.3±3.3 (3)
Cl efflux	37.5±6.4 (4)	−2.5±6.4 (4)‡

* Mean, SE, and number of measurements in parentheses.

‡ $p < 0.01$.

§ $p < 0.05$.

DISCUSSION

The most important problem emerging from these results is the large discrepancy between the net ion fluxes and the I_{sc}. Although the combined net influxes of Na and K are nearly as large as the I_{sc}, the net influx of Cl neutralizes much of the positive charge carried by Na and K (Fig. 4 and Table II). Thus more than one-half of the I_{sc} remains unaccounted for. Many other ions which might undergo net transport are present in the system, however; e.g., Ca 2, Mg 12, SO_4 8, and HCO_3 0.2 mEq/liter (approximate concentrations). Movements of H and OH ions might be important also. The rapid drop in I_{sc} with darkness (Fig. 2) indicates that most of the net charge transport is closely linked to photosynthesis.

In normal *Valonia* active extrusion of Na and probably active uptake of K occur at the plasmalemma, and active influxes of both Na and K occur at the tonoplast (21). The evidence for these ion pumps is that Na efflux and K influx at the plasmalemma and Na and K influx at the tonoplast occur against rather large electrochemical potential gradients under flux-equilibrium conditions. In short-circuited *Valonia* the electrochemical activities of protoplasmic ions cannot be accurately assessed, because neither the PD nor the concentrations were measured under short-circuit conditions. The net influxes of Na and K in short-circuited cells suggest active transports at either plasmalemma or tonoplast, however. When the vacuole PD is +40 mv the net influxes of Na and K at the tonoplast are almost certainly uphill; i.e., from a lower to a higher electrochemical potential. Thus active influxes of both Na and K at the tonoplast are suggested, which is consistent with the results on normal cells (21). The nature of Cl transport is uncertain. In normal *Valonia* Cl influx from seawater to vacuole appears to be a passive process, based on the similarity between measured and predicted flux ratio calculated by the Ussing-Teorell equation (21, 40, 42). In short-circuited *Valonia*, however, the net influx of Cl suggests active transport from external solution to vacuole (Table II).

Another complication in the interpretation of these results is that active transport may occur at the membranes surrounding intracytoplasmic vesicles as well as at the outer or short-circuited borders of the protoplasm. It is suggested by Steward and Sutcliffe (36, 37) that this process is a possible mechanism of salt transport in *Valonia* and other plant cells, and it is discussed further by MacRobbie (27, 28) in relation to an apparent coupling between K and Cl uptake into the vacuole of *Nitella.* Recent electron micrographs of the giant algal cells *Chara* (14) and *Chaetomorpha* (17) show numerous cytoplasmic vesicles adjacent to the tonoplast. If part of the salt transport across the protoplasm is via these vesicles, in which the PD cannot be short-circuited, then a net transport of both anions and cations will occur regardless of which species is actively transported. If this process occurs in *Valonia*, it might account for the discrepancy between the apparently passive net influx of Cl in normal cells and the apparently active net influx in short-circuited cells, and it would also provide a mechanism for possible coupling of salt and water fluxes across the protoplast.

The origin of the membrane potentials in *Valonia* is of interest because *Valonia*, unlike most other plant cells, has a positive vacuole potential, about +17 mv in normal cells and +74 mv in cells perfused and bathed with artificial sap. The plasmalemma PD may be a diffusion potential controlled largely by the movement of K down its concentration gradient. The plasmalemma in normal cells is more permeable to K than to either Na or Cl, and the K concentration gradient is more than sufficient to account for the PD of −71 mv (Table I) (21). Furthermore, the plasmalemma is rapidly depolarized and reverses in sign when cells are bathed in high K solutions; i.e., natural or artificial sap. The immediate rise of the vacuole PD from about +17 mv to about +90 mv when cells are immersed in artificial sap (16, footnote 2) can be explained as a rapid depolarization of the plasmalemma with no immediate change in the tonoplast PD.

The tonoplast PD, on the other hand, may be due partly to the electrogenic activity of inward cation transport. The concentration gradients for Na and K across the tonoplast are in the wrong direction to account for the PD of 80–90 mv, cytoplasm negative to vacuole (21). Chloride diffusion might contribute to the tonoplast PD, but replacement of vacuolar Cl with propionate or benzene-sulfonate causes the PD to change initially in a positive direction (footnote 2), which is opposite to the change expected for a Cl diffusion potential. The rapid drop in both the PD and I_{sc} with darkness is consistent with the hypothesis of an electrogenic pump. Additional information is needed, however, especially concerning the origin of the short-circuit current in *Valonia*.

I thank Professors D. C. Tosteson and Jack Dainty for advice and encouragement, Dr. J. W. Moore for the use of his electrode puller, and Dr. L. R. Almodovar for supplies of *Valonia*.
This work was supported by the United States Fish and Wildlife Service, United States Atomic Energy Commission, and a postdoctoral fellowship from the United States Public Health Service, Division of General Medical Sciences.

Received for publication 11 November 1966.

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Migratory Behavior of Sockeye Salmon Fry and Smolts[1]

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ABSTRACT

Considerable new data on the characteristics of sockeye fry and smolt migrations, direct underwater observations of migrating smolts, and a review of the literature are presented here with a synthesis, evaluation, and interpretation of possible survival advantages of these phenomena. Most fry migrations from spawning areas to nursery lakes take place in the spring, when harsh winter conditions in lakes are moderating and the growing season is beginning. Smolt migrations to salt water closely follow spring breakup of the ice and warming of the lake water. The time of smolt migration is correlated closely with latitude: migration is earlier in southern streams than in northern streams. The duration of seasonal migration appears to be strongly related to travel distance to the trunk river outlet. The smolt exodus is rapid and regular in single-lake systems but irregular and extended in multilake or multibasin systems. The frequency distribution of smolts migrating from two-lake or two-basin systems is usually bimodal. Most migrations commence as water temperatures near 40 F and are over when temperatures approach 50 F. Migrations of smolts and especially fry are mainly confined to the darkest hours of the night. In general, in any one season, the oldest and the largest smolts in each age-group migrate first. Other factors, such as the thickness of the ice, effectiveness of solar radiation in melting ice and warming water, and daily weather (including sunlight and wind), also influence seasonal and diel migration patterns. Underwater observations of smolts at night during migration show that they are schooled, travel in the upper water levels in shallow rivers and deeper (but not near the bottom) in deeper rivers, and usually face downstream and swim as they migrate. During migrations, fry and smolts are both often subjected to a depensatory mortality from intense predation by birds and fish. A factor disporportionately affecting different smolt populations is the length and number of restricted passages along the route to the ocean. Smolts migrating in multilake systems must encounter heavier predation than smolts migrating from single-lake systems. Predation is probably minimized en route because of innate migratory behavior patterns. Exceptions to the general migratory behavior of fry and smolts are described to show the wide range in behavioral response to variable environmental situations.

INTRODUCTION

The freshwater life history of young sockeye salmon (*Oncorhynchus nerka*) usually includes two relatively short periods of active migration: fry migrate to nursery lakes after emerging from stream, river, or lake spawning gravel; after a period that may last as long as 3 years, they leave the lakes as smolts and migrate to salt water. During these migrations the fry and smolts are confined to narrow pathways in the stream or trunk rivers. Predators congregate in and around these restricted pathways to prey on the migrants. Very likely migratory behavior with survival advantages has evolved.

Although sockeye fry are known to migrate upstream into lakes from outlet rivers (e.g. Karluk River, Alaska, and Chilko River, British Columbia

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[1] Received for publication June 15, 1967.

J. Fish. Res. Bd. Canada, **24**(10), 1967.
Printed in Canada.

(Andrew and Geen, 1960)), downstream migration into lakes is more common. Certain facets of the behavior of sockeye fry migrating downstream to nursery lakes have already been reported (McDonald, 1960; Hartman et al., 1962). Briefly, the fry face downstream and swim actively rather than drift with the current, mainly during darkness, i.e. they are negatively rheotactic and phototactic. During daylight they usually seek cover along banks and in the streambed. Neave (1955) and McDonald (1960) reported similar behavior for fry of pink salmon (*O. gorbuscha*) and chum salmon (*O. keta*).

Less information, however, is available concerning the behavior of smolts during migration. It is known that sockeye smolts migrate chiefly at night. Foerster (1937), Kerns (1961), Burgner (1962), and Hoar (1954) studied smolts and found them to be negatively phototactic but positively rheotactic, i.e. they avoid strong light and move against the current. Hartman et al. (1962) found this behavior typical for young sockeye after they schooled in the lake, and postulated that positive rheotaxis is the dominant factor that confines juvenile sockeye to lake nursery areas until transformation to smolts.

Temperature, light intensity, lake wave action, and river discharge all have been considered as external releasers for physiologically ready salmonid smolts to migrate (Baggerman, 1960). Foerster (1937) determined that the seaward migration of sockeye from Cultus Lake was correlated with air and water temperatures during the months immediately preceding migration. He also found that the numbers leaving the lake increased on bright calm days and decreased on dull cool days. Burgner (1962) also reported that the initiation and cessation of the annual spring migrations of sockeye smolts from the Wood River Lakes, Alaska, were closely related to the increase in water temperature.

This paper presents considerable new data on the characteristics of migrations of fry and smolts in many lakes in southwestern Alaska (Fig. 1) and British Columbia. We include information from direct underwater observation of sockeye behavior in the Naknek and Karluk River systems. Much unpublished material and published reports are reviewed. All information is synthesized into a comprehensive examination of migratory behavior, and the possible survival advantages of migratory behavior are discussed.

METHODS

Material on the timing, number, age, and size composition of smolts migrating from important sockeye-producing systems in southwestern Alaska was obtained from unpublished and published reports by the Bureau of Commercial Fisheries, the Fisheries Research Institute of the University of Washington, and the Alaska Department of Fish and Game. Material on fry migratory behavior in certain tributaries at Brooks and Karluk Lakes was obtained by the Bureau of Commercial Fisheries.

Data on rheotactic responses, schooling behavior, and stream depth preference of migrating smolts were obtained by direct underwater observations by biologists wearing neoprene rubber suits. Observations were made

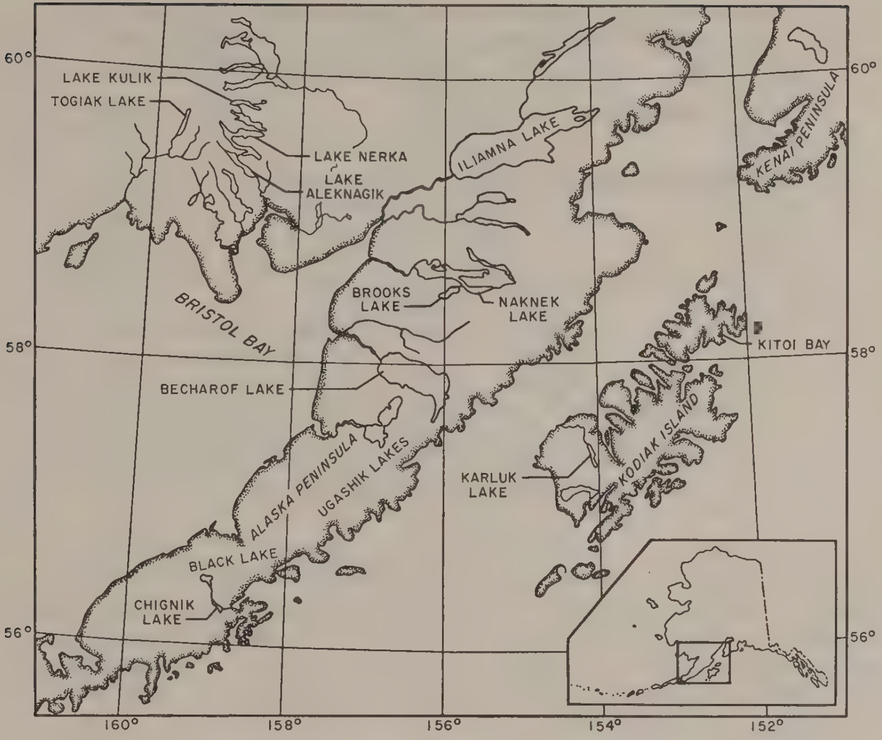

60°
LAKE KULIK
TOGIAK LAKE
LAKE NERKA
LAKE ALEKNAGIK
ILIAMNA LAKE
KENAI PENINSULA
60°
BRISTOL BAY
BROOKS LAKE
NAKNEK LAKE
58°
KITOI BAY
58°
BECHAROF LAKE
ALASKA PENINSULA
UGASHIK LAKES
KODIAK ISLAND
KARLUK LAKE
BLACK LAKE
CHIGNIK LAKE
56°
56°
160°
158°
156°
154°
152°

FIG. 1. Sockeye salmon nursery lakes in southwestern Alaska.

during late twilight, when sufficient light remained for observation, and during darkness, with underwater hand lamps. Sometimes lamps were turned on only at intervals for spot checking; at other times they were operated constantly. Underwater observations were made in Brooks, Grosvenor, Coville, and Naknek Rivers of the Naknek system and Karluk River of the Karluk system. The diversity of these environments permitted observations in a variety of water depths, velocities, and turbidities.

SEASONAL MIGRATIONS OF FRY AND SMOLTS

FRY

Data on sockeye fry migrations from stream spawning areas to nursery areas in Brooks and Karluk lakes have been collected for a number of years.

The seasonal migration of fry from Hidden Creek, a tributary to Brooks Lake, did not deviate significantly in 1961–64 from that of 1960, described by Hartman et al. (1962). Migrations start in late April, reach their midpoint around May 13, and are essentially completed by about May 25 (Fig. 2). Although spawning takes place during early August in both Hidden Creek

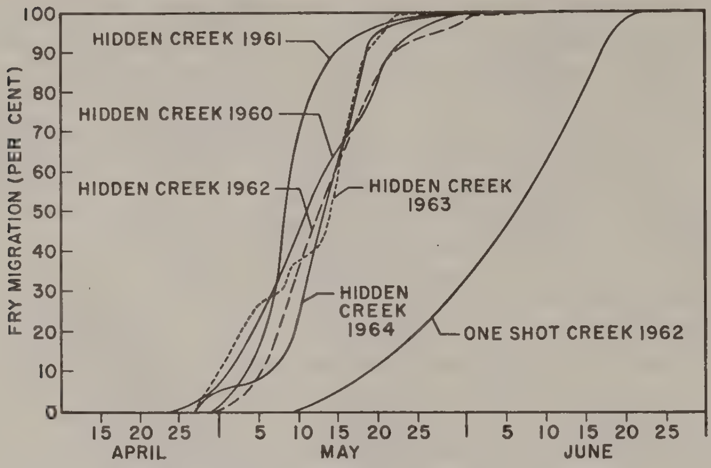


FIG. 2. Cumulative seasonal migration of sockeye fry in per cent to Brooks Lake from Hidden Creek (1960–64) and One Shot Creek (1962).

and One Shot Creek (another tributary to Brooks Lake), the peak of fry migration from One Shot Creek was more than 3 weeks later in the spring of 1962 (Fig. 2). Some of the water in One Shot Creek is from springs, and the stream is often 2 or 3 C colder in mid- and late summer than Hidden Creek. This difference evidently results in slower embryological development and a later departure of fry.

The seasonal appearance of adult sockeye returning to Karluk Lake to spawn is bimodal (Barnaby, 1944). Small lateral tributary streams receive only summer spawners; lake-beach spawning areas receive only fall spawners; and terminal tributary streams receive both summer and fall spawners.

Fry migrations from the tributaries of Karluk Lake that are seeded by summer spawners, such as Grassy Point Creek and Upper Thumb River, begin about 2 weeks earlier, on the average, than migrations at Brooks Lake (Fig. 2, 3). This difference may be due to Karluk Lake's more southerly latitude and the likelihood of earlier warming each spring.

Spawning normally occurs in both summer and fall in Canyon Creek and Meadow Creek, and the fry emerge in separate early spring and late spring migrations (Fig. 4). About 60 days separate the midpoints of the two spawning periods and the two spring migrations of fry. The timing of the early spring migration at Meadow Creek in 1962 was strikingly different from that in 1963 (Fig. 4) and also different from the six other early spring migrations observed in tributaries of Karluk Lake (Fig. 3, 4). In 1963, 50% had migrated from Meadow Creek by May 3 which is normal timing. Yet in 1962 the midpoint date was May 24. The most reasonable explanation for the difference is that water temperatures during the 1961–62 incubation period at Meadow Creek were abnormally cold.

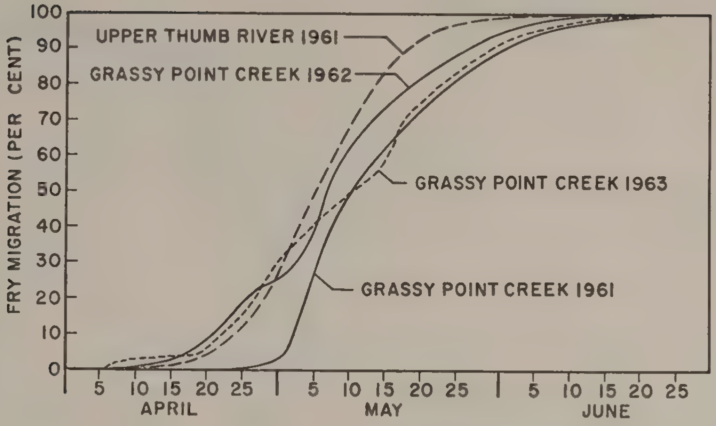


FIG. 3. Cumulative seasonal migration of sockeye fry in per cent to Karluk Lake from Grassy Point Creek (1961–63) and Upper Thumb River (1961). These fry are progeny of summer spawners.

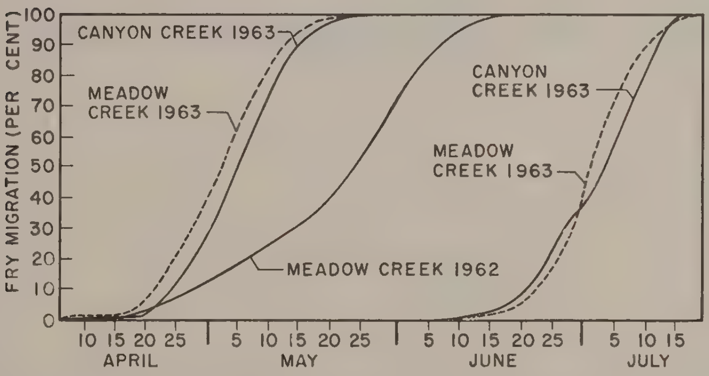


FIG. 4. Cumulative seasonal migration of sockeye fry in per cent to Karluk Lake from Meadow Creek (1962–63) and Canyon Creek (1963). These fry are progeny of both summer and fall spawners.

SMOLTS

Seasonal migrations of sockeye smolts differ considerably among the lake systems but are usually fairly consistent from year to year within each system. Smolts migrate at Cultus Lake in late April (Foerster, 1937; see Fig. 5) and in late June and early July at Lake Tazlina on the Copper River (Thompson, MS, 1964). Lakes in which migration occurs on dates between these extremes are: Lakelse Lake (Fig. 6), Chignik Lake (Fig. 7), Karluk Lake (Fig. 8), Ugashik Lake (Fig. 9), Becharof Lake (Fig. 10), Brooks Lake (Fig. 11), Naknek Lake (Fig. 12), Iliamna Lake (Fig. 13), and Lake Aleknagik (Fig. 14). The spacing along the abscissal scales is identical in Fig. 5–14, but

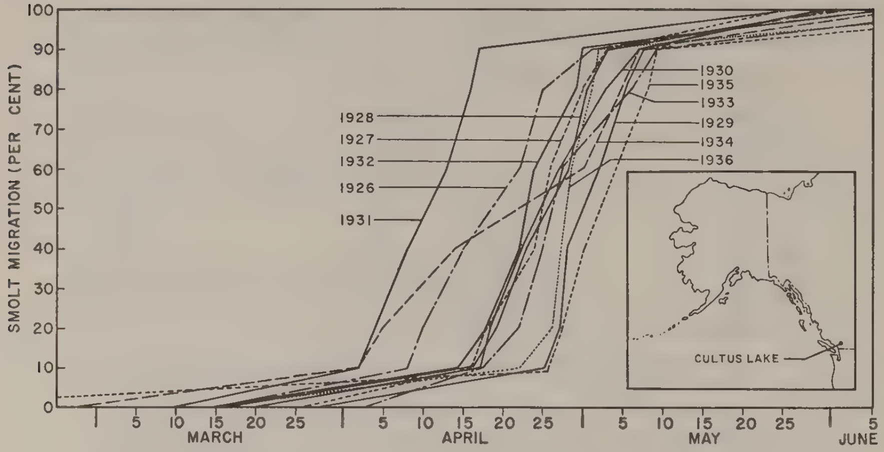


FIG. 5. Cumulative seasonal migration of sockeye smolts in per cent from Cultus Lake for 1926–36 (after Foerster, 1937).

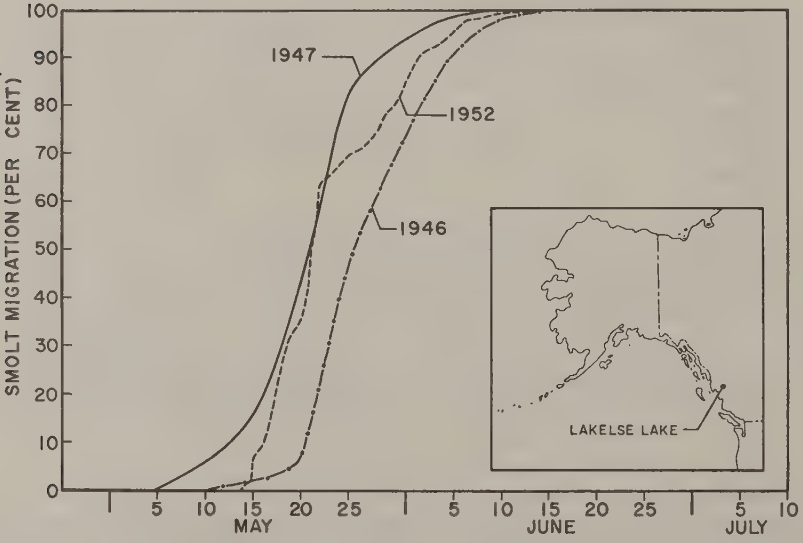


FIG. 6. Cumulative seasonal migration of sockeye smolts in per cent from Lakelse Lake (data for 1946–47 from Brett and McConnell (1950), and for 1952 from Foerster (1952)).

different calendar periods are shown on each, according to the timing of migration.

The average seasonal timing of migrations in 16 sockeye-producing systems examined (Table I, Fig. 15) shows a strikingly close correlation with

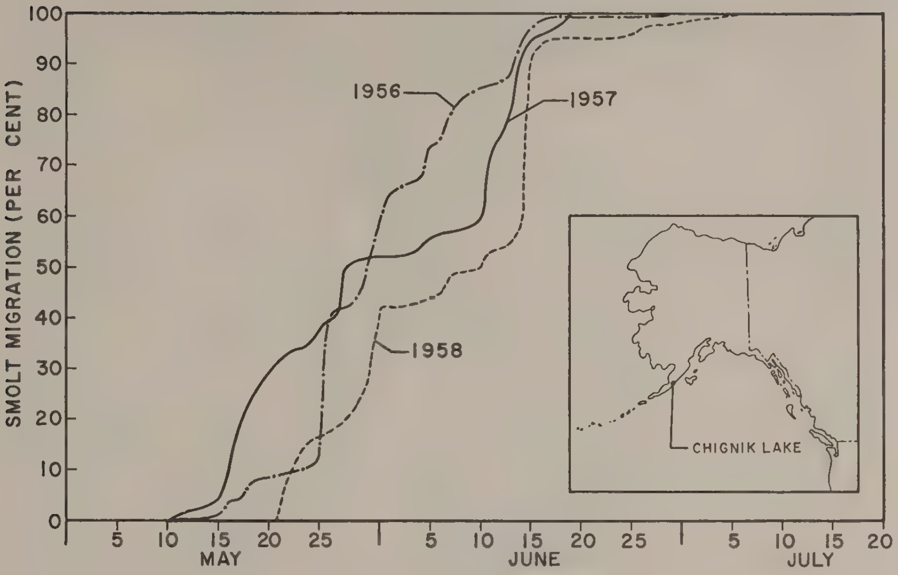


FIG. 7. Cumulative seasonal migration of sockeye smolts in per cent from Chignik Lake (after Roos, 1958, 1959).

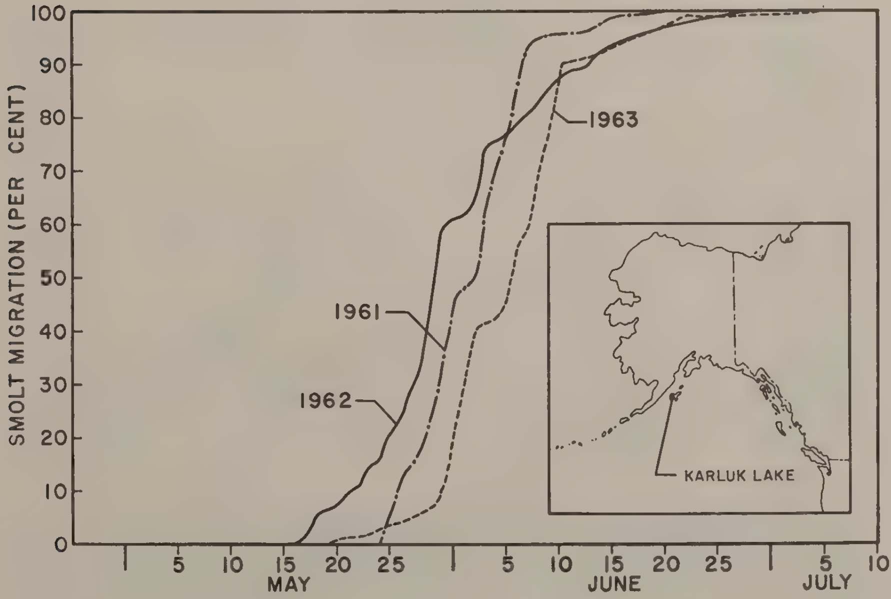


FIG. 8. Cumulative seasonal migration of sockeye smolts in per cent from Karluk Lake.

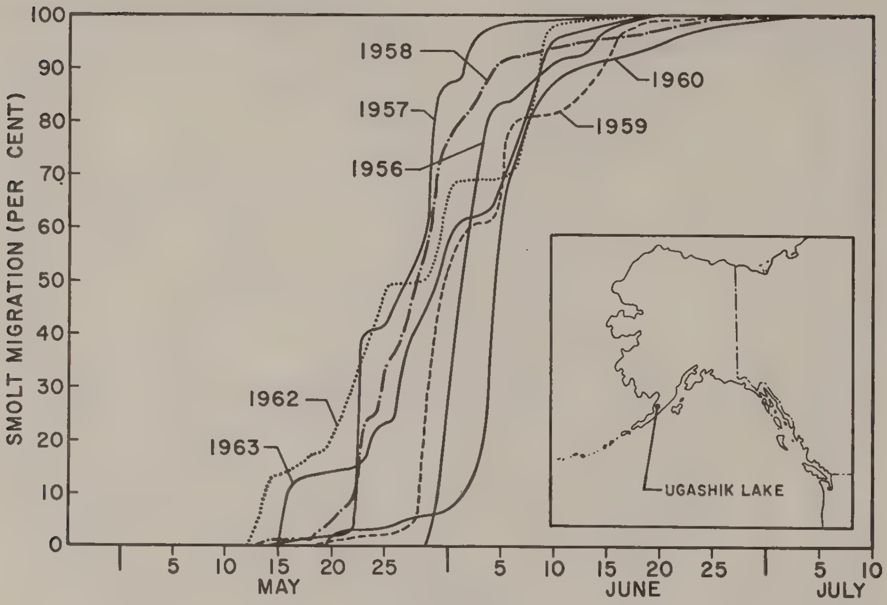


FIG. 9. Cumulative seasonal migration of sockeye smolts in per cent from Ugashik Lake.

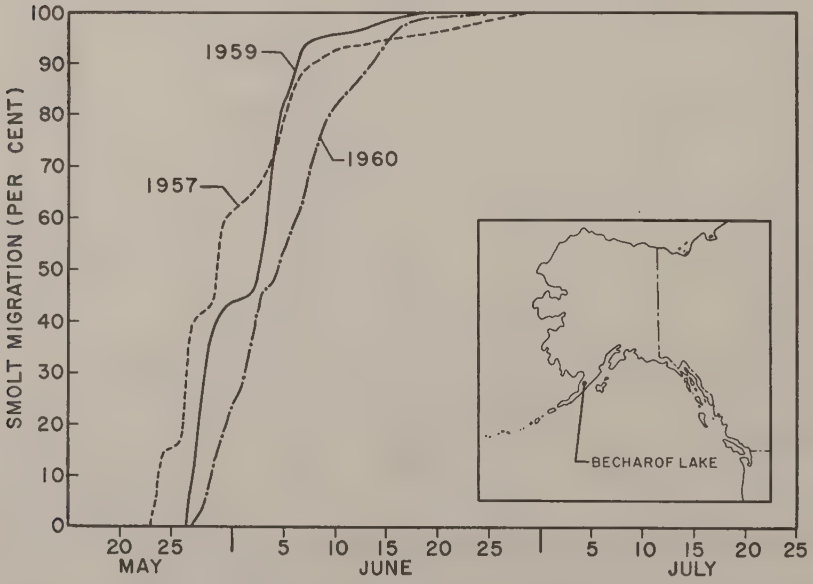


FIG. 10. Cumulative seasonal migration of sockeye smolts in per cent from Becharof Lake.

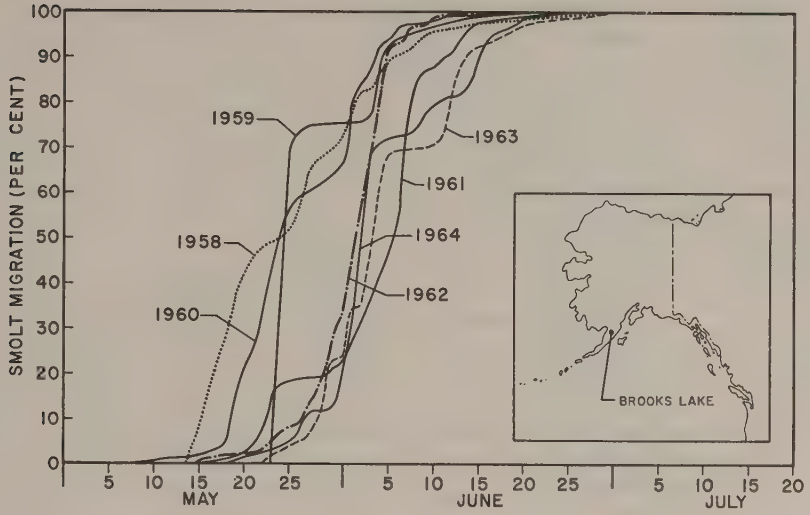


FIG. 11. Cumulative seasonal migration of sockeye smolts in per cent from Brooks Lake.

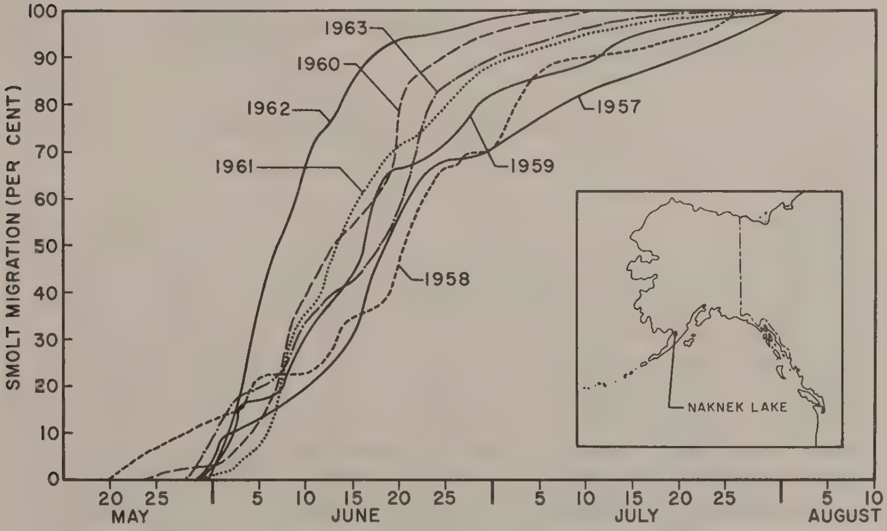


FIG. 12. Cumulative seasonal migration of sockeye smolts in per cent from Naknek Lake.

latitude (Fig. 16). Migrations occur progressively later in the season as the distance north from Cultus Lake, British Columbia, increases. The seasonal pattern for the Bolshaya River, on the western side of Kamchatka Peninsula (Semko, 1954), also fits the relationship shown by migrations in North American streams.

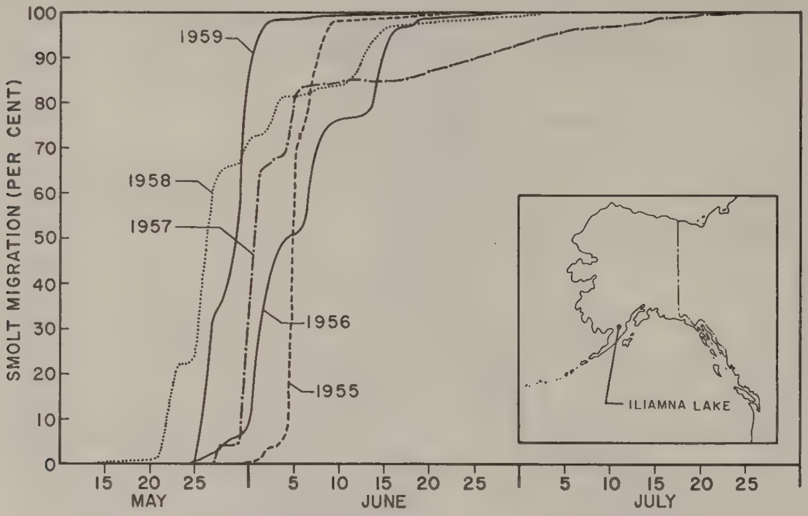


FIG. 13. Cumulative seasonal migration of sockeye smolts in per cent from Iliamna Lake (after Kerns, 1961).

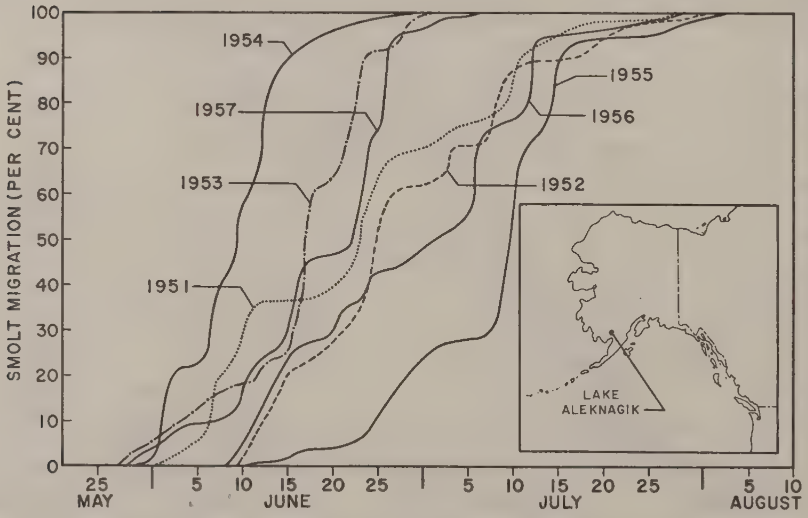


FIG. 14. Cumulative seasonal migration of sockeye smolts in per cent from Lake Aleknagik (after Burgner, 1962a).

Several authors (e.g. Chamberlain, 1907; Foerster, 1937; Burgner, 1962) have mentioned the relationship between ice breakup, warming of water temperatures, and initiation of smolt migration. Progressively increasing solar radiation in the spring in the Northern Hemisphere obviously bears

TABLE I. Average dates by which 50% of sockeye smolts have left lake systems.

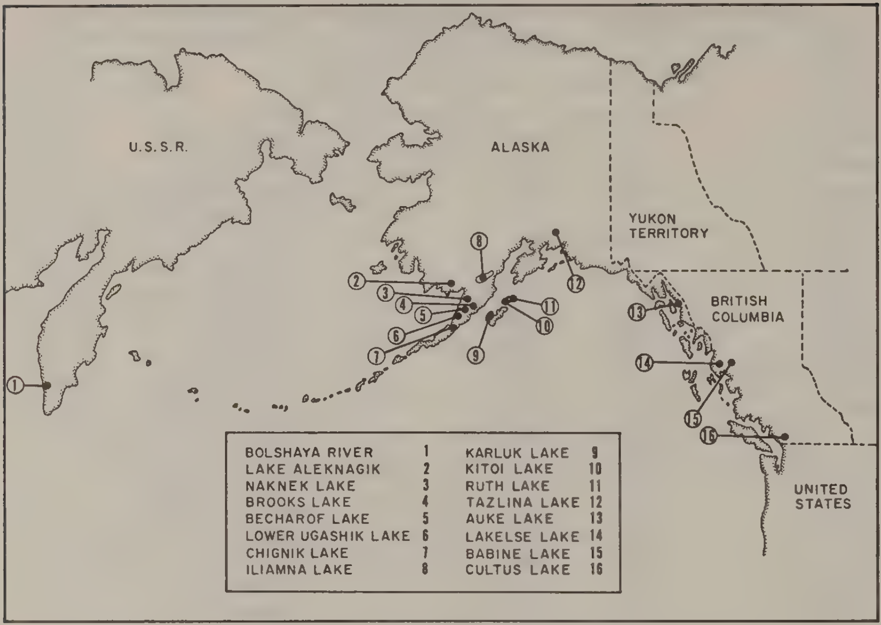
Lake system	N latitude	Date[a]	No. of years of observation	Source
Cultus	49° 0′	April 25	11	Foerster (1937)
Bolshaya River	52°15′	May 12	Several	Semko (1954)
Lakelse	54°32′	May 23	3	Foerster (1952), Brett and McConnell (1950)
Babine[b]	54°50′			
Early		May 13	6	Anon. (MS, 1964)
Late		June 4	13	Anon. (MS, 1964)
Chignik	56°16′	June 3	3	Roos (1958)
Karluk	57°20′	June 3	3	Present paper
Lower Ugashik	57°35′	May 30	6	Jaenicke (MS, 1963)
Becharof	57°55′	June 1	3	Jaenicke (MS, 1963)
Kitoi	58°15′	June 5	9	Meehan (MS, 1964)
Ruth	58°15′	June 14	6	Meehan (MS, 1964)
Auke	58°23′	May 28	2	D. T. Hoopes (personal communication)
Brooks	58°28′	May 31	7	Present paper
Naknek	58°39′	June 16	7	Jaenicke (MS, 1963)
Iliamna	59°30′	June 2	9	Kerns (1961) and personnal communication
Aleknagik	59°35′	June 22	7	Burgner (1962)
Tazlina	61°55′	July 1	Several	Thompson (MS, 1964)

[a] Actual average midpoint of migration where known, or best estimate from source.
[b] Dates given for distinct early and late smolt migrations.

directly on ice breakup and warming of the water (and, in turn, on smolt migration).

Local climate and characteristics of individual lakes could account for minor deviations from the general relation between latitude and migration timing. For example, the seasonal migration at Iliamna Lake is relatively early for its latitude (Fig. 15). O. E. Kerns (personal communication) suggested that the ice cover on Iliamna Lake, the largest lake in Alaska, is relatively unstable because it often is not formed completely until mid-December. Spring winds with long fetches usually cause a rapid breakup — often in only 3 or 4 days. As a result, migrations begin relatively earlier here than in such nearby lakes as Naknek, Ugashik, and Aleknagik, where freezeup is earlier, ice is more stable, and winds are not as effective in breaking up the ice.

The seasonal migration in single-lake and multilake or multibasin systems appears strongly related to travel distance to the trunk river outlet. For single-lake systems the smolt exodus is speedy. The slopes of the curves depicting the progress of migration are steep for such lakes as Cultus (Fig. 5), Lakelse (Fig. 6), Karluk (Fig. 8), Becharof (Fig. 10), Brooks (Fig. 11), and Iliamna (Fig. 13). In any one year most of the migration occurs in a few days.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ALASKA
YUKON TERRITORY
BRITISH COLUMBIA
UNITED STATES
BOLSHAYA RIVER 1
LAKE ALEKNAGIK 2
NAKNEK LAKE 3
BROOKS LAKE 4
BECHAROF LAKE 5
LOWER UGASHIK LAKE 6
CHIGNIK LAKE 7
ILIAMNA LAKE 8
KARLUK LAKE 9
KITOI LAKE 10
RUTH LAKE 11
TAZLINA LAKE 12
AUKE LAKE 13
LAKELSE LAKE 14
BABINE LAKE 15
CULTUS LAKE 16

FIG. 15. Sockeye salmon-producing systems treated in analysis of the seasonal timing of sockeye smolt migrations.

For multibasin systems it seems logical that the exodus of smolts would extend over a longer period of time. The migration curves from Naknek Lake (Fig. 12) and Lake Aleknagik (Fig. 14) show an extended period of migration. These lake outlets are trunk rivers for multilake systems, and the migration is extremely irregular — a result of variations in timing of the migrations from each lake and in magnitude of the different smolt populations. Burgner (1962) concluded from seasonal changes in length-frequency distribution of smolts that the first migrants were from the lowest lake in the Wood River system, Lake Aleknagik, and that the later migrants were from the upper lakes and had been delayed by travel distances.

Johnson and Groot (1963) reported two peaks in the migration from Babine Lake (Fig. 16). Groot (1965) shows this for 4 years of data. They assumed that the migrations began throughout this multibasin system at the same time. If so, their data on tag recovery and speed of migration suggest that the first migration peak represented smolt populations from the vicinity of the outlet, consisting of Nilkitkwa Lake and the North Arm of Babine Lake; and the second migration peak represented smolts from the more distant region, the main basins of Babine Lake. The average date between these two peaks was May 24 and fell almost perfectly in line in the relation to latitude (Fig. 16).

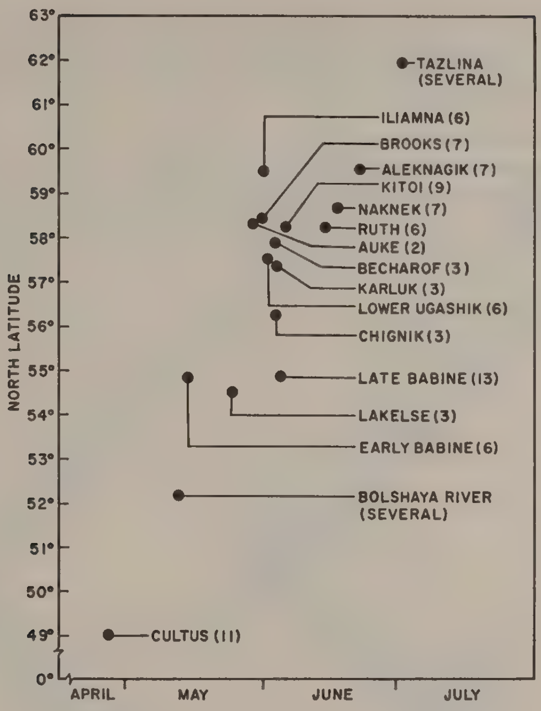


FIG. 16. Average date by which 50% of the spring sockeye smolts had migrated from lake systems located at different latitudes. Numbers in parentheses show number of years of observation.

Travel distance may not be the only cause of bimodal migrations from multilake or multibasin systems. Other important factors such as age and size of smolts and the tendency for older and larger smolts to migrate first (see section under heading "Biological and Physical Factors Associated with Smolt Migrations") must also be considered.

The two-lake Chignik system appears to have a bimodal migration. Bimodality was especially evident in 1957 and 1958 at the trunk river outlet from Chignik Lake (Fig. 7). Studies of age and length-frequency distributions and scale characteristics of the smolts (Roos, MS, 1958; Narver, MS, 1963) showed that usually the early migrants are 2 years old and are from Chignik, the lower lake; and the later migrants are 1 year old and are from Black, the upper lake.

DIEL MIGRATIONS OF FRY AND SMOLTS

FRY

Sockeye fry emerge from the gravel primarily at night (Heard, 1964) and migrate primarily at night (McDonald, 1960; Hartman et al., 1962).

We observed the seasonal diel migration patterns of sockeye fry from various tributaries for 6 years at Brooks Lake and 5 years at Karluk Lake, and present here data from four migrations that illustrate these and other related phenomena.

The observations at Brooks Lake, where fry counts were made hourly, showed clearly that nearly all migration was confined to the hours between 2100 and 0200 (Fig. 17, 18). At Karluk Lake, where counts were usually made at 2-hr intervals starting at 1900 hours early in the season and 2000 hours later in the season, the bulk of the migration occurred before 2400 (Fig. 19, 20). Migration started nearly an hour earlier at Karluk Lake than at Brooks Lake on the same dates. Karluk Lake is 1.5 degrees of longitude east of Brooks Lake, but this accounts for only a difference of about 6 min in time of sunset. A possible explanation for the hour's difference is that all creeks studied at Karluk Lake enter on the west side, where a high ridge of mountains blocks sunlight during the early evening. The creeks at Brooks Lake are on the northeast side of the lake and are fully exposed to sunlight later into the evening.

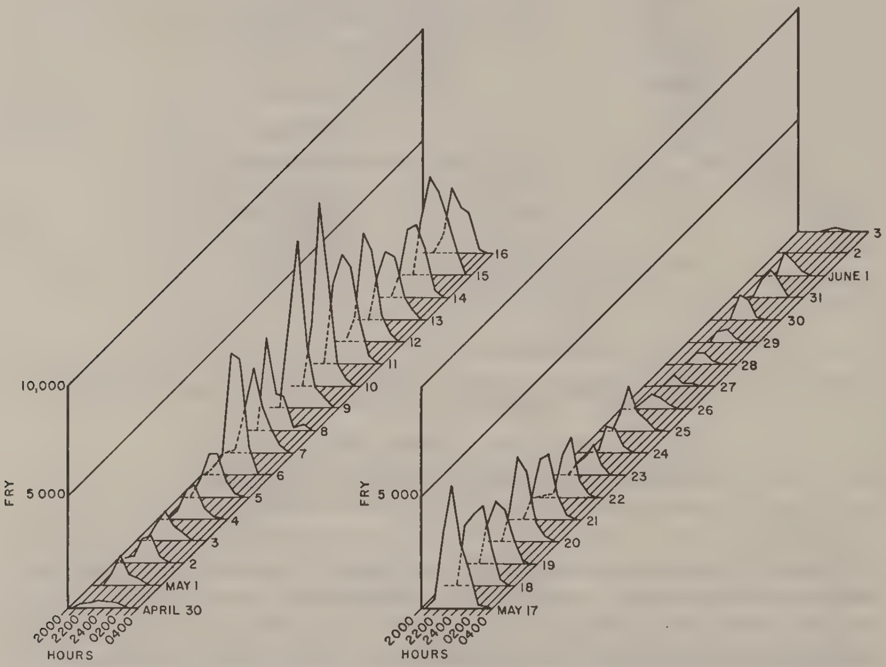


FIG. 17. Migration of sockeye salmon fry from Hidden Creek to Brooks Lake during the nights, April 30–June 3, 1962.

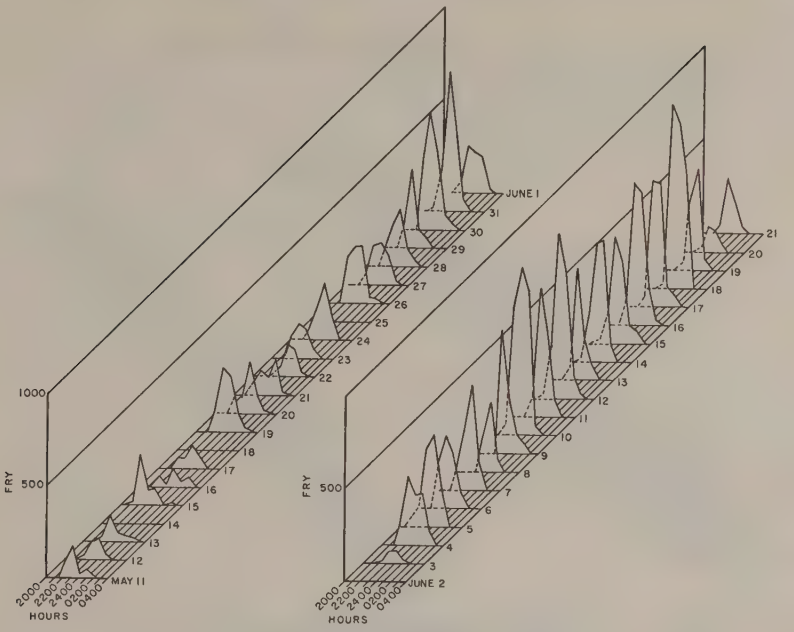


FIG. 18. Migration of sockeye salmon fry from One Shot Creek to Brooks Lake during the nights May 11–June 21, 1962.

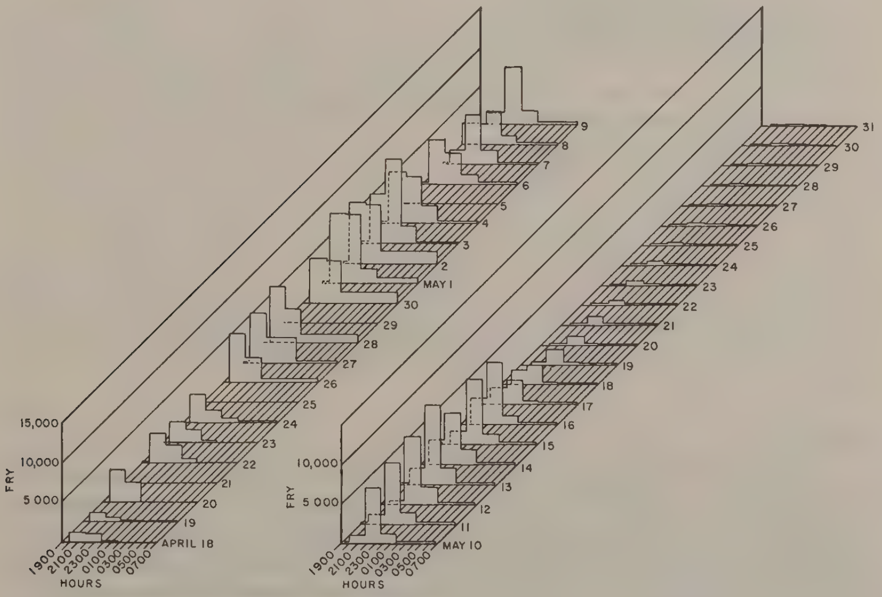


FIG. 19. Migration of sockeye salmon fry from Canyon Creek to Karluk Lake during the nights, April 18–May 31, 1963.

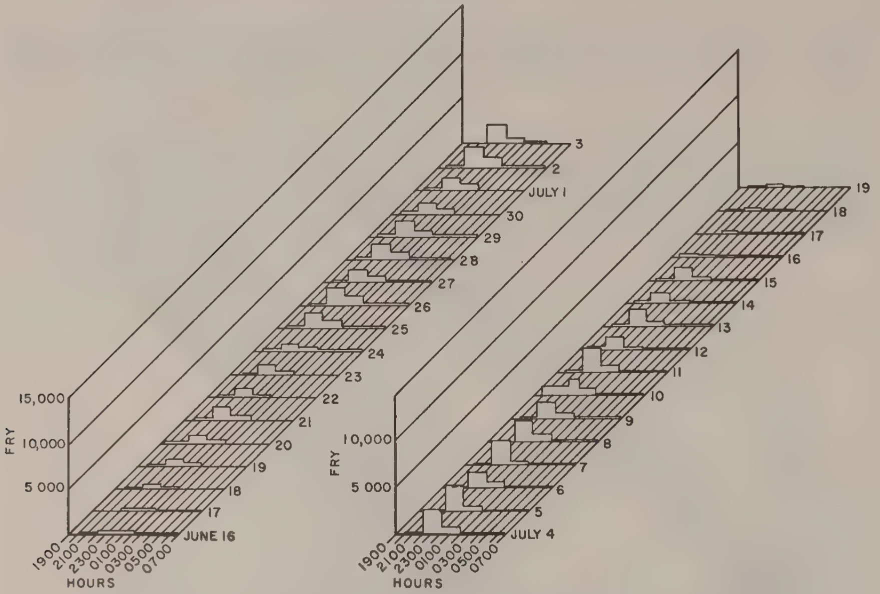
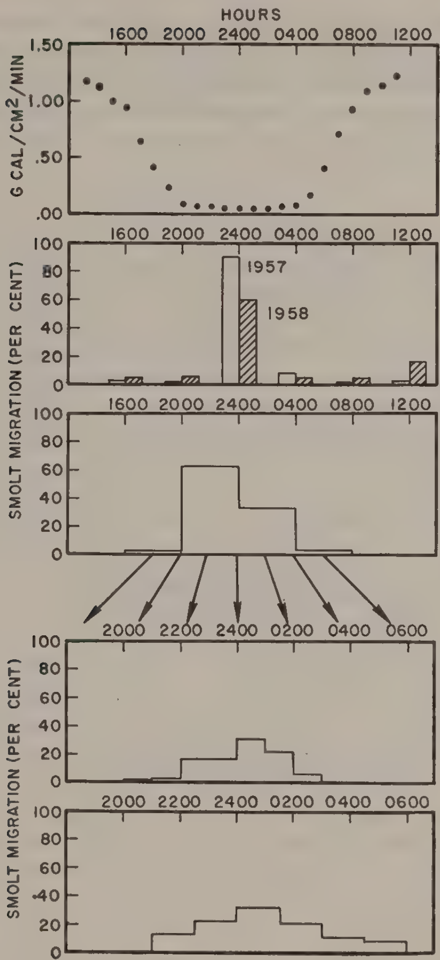


FIG. 20. Migration of sockeye salmon fry from Canyon Creek to Karluk Lake during the nights, June 16–July 19, 1963.

Another phenomenon evident for all observations on fry migrations, and also observed by McDonald (1960) and Hartman et al. (1962), is the shortening of the daily migration period and its shift to later hours as the season progresses and dusk comes later and dawn earlier. The clearest example was at Canyon Creek in 1963. The 1963 spring migration of fry produced from spawning in the summer of 1962 extended over a number of hours during late April and early May, and the peak of nightly migrations was about 2100 hours (Fig. 19). By late May the period of nightly migration was shorter, and the peak shifted to 2200 or later. The 1963 late spring migration of fry produced by spawning in the fall of 1962 continued to show the shorter period of migration, and by late June the peak had shifted to about 2300 hr (Fig. 20). Substantial migrations did not extend far enough past the summer solstice to show if nightly migration periods lengthened or peaks shifted back toward an earlier hour as daylight decreased.

SMOLTS

Most Bristol Bay sockeye smolts migrate from their lake systems during the darkest hours, 2000–0400 (Fig. 21). Only about 4% of the total migration occurs during other hours. At Karluk Lake in 1963 about 96% of the smolts migrated between 2000 and 0300 hours, and in 1964 about 92% migrated during these hours. Nocturnal migration is also the general rule at Lake Aleknagik where Burgner (1962) found that 95% of the smolts caught during 17 days



TYPICAL DIEL PATTERN OF INCIDENT SOLAR RADIATION AROUND JUNE 2 AT BROOKS LAKE AS MEASURED BY A CONSTANT RECORDING PYRHELIOMETER.

DIEL MIGRATION PATTERN IN PER CENT OF SOCKEYE SMOLT LEAVING ILIAMNA LAKE IN 1957 AND 1958 (BASED ON 21 DAYS OF OBSERVATION BY KERNS, 1961).

DIEL MIGRATION PATTERN IN PER CENT OF SOCKEYE SMOLT LEAVING BROOKS LAKE IN 1961, SIX DAYS OF SAMPLING SUMMARIZED.

AVERAGE MIGRATION PATTERN BETWEEN 2000 AND 0300 HOURS IN PER CENT FOR SOCKEYE SMOLT LEAVING BROOKS LAKE, 1961, FOR 25 NIGHTS OF SAMPLING.

AVERAGE MIGRATION PATTERN BETWEEN 2100 AND 0600 HOURS IN PER CENT FOR SOCKEYE SMOLT LEAVING NAKNEK LAKE, 1959–1963, 202 NIGHTS OF SAMPLING SUMMARIZED (JAENICKE, MS, 1963).

Fig. 21. Diel patterns of solar radiation at Brooks Lake, diel sockeye smolt migration at Iliamna Lake and Brooks Lake, and nocturnal smolt migration pattern at Brooks and Naknek lakes.

of round-the-clock fishing in 1951 were taken between 2100 and 0200 hours. Groot (1965) presents data for 6 days for smolt migrations from Great Central Lake in British Columbia in 1960. Migrations began after sunset and were confined mainly to the period 2000–2400 hr. Kerns (1961) observed similar behavior in 1957 at the outlet to Iliamna Lake (Fig. 21) when 91% of the migration took place between 2200 and 0200 hr. He found, however, during 1958, when the migration was extremely heavy, that about 38% of the smolts caught in 9 days of round-the-clock fishing were taken between 0200 and

2200 hours. Kerns suggested that carryover of the migration into daylight hours was directly related to the number of migrants. Possibly the capacity of the outlet stream to accommodate migrants during darkness was exceeded. H. W. Jaenicke (personal communication) suggested that daylight migrations of smolts such as he observed at Naknek River may also be related to heavy fog, cloudbursts, or heavy onshore winds that cause high turbidity in the outlet.

The peaks of nocturnal smolt migration in the latitude of the Alaska Peninsula generally are around midnight. Nocturnal migration of smolts at Brooks and Naknek Lakes is greatest between 2300 and 0200 hr (Fig. 21). The peaks vary with seasonal and daily changes in light. In 1957 and 1958, when the migration from Iliamna Lake took place in May (Kerns, 1961), darkness set in around 2200 hr, and the peak migration was between 2200 and 2300 hr. In 1955 and 1956, when the migration took place chiefly in early June, darkness set in around 2300 hr and the peak migration was between 2300 and 2400 hr. Farther south on the Alaska Peninsula at Chignik Lake, Thorsteinson and Roos (MS, 1958) detected a shift in peak of migration from 2300 to 2400 hr as the season progressed. They also noted a tendency for the evening migration peak to occur earlier on dark, overcast days.

The timing of the peak migration from Naknek Lake (Fig. 21) was usually later in the evening than at Brooks Lake, Iliamna Lake, Lake Aleknagik, or Chignik Lake. Smolts were sampled in the outlet near the lake, except at Iliamna Lake, where smolts were sampled about 2 miles downstream from the lakes, and at Naknek Lake, where smolts were sampled about 8 miles downstream from the lake. Presumably smolts migrated from Naknek Lake during the first hours of darkness as at other lakes, but the distance of 8 miles from the lake outlet to the sampling site caused the later peak.

H. W. Jaenicke (personal communication) has observed at Naknek River that after the summer solstice on June 21, and especially by mid- and late July, the peak of migration shifts to an earlier hour as darkness comes earlier in the evening.

BIOLOGICAL AND PHYSICAL FACTORS ASSOCIATED WITH SMOLT MIGRATIONS

A number of biological and physical factors have been related by other scientists to seasonal and diel migration of smolts. Among them have been age structure of the smolt population, solar radiation, water temperature, ice breakup, wind intensity and direction, cloud cover, rainfall, and water level. Certain important points are briefly reviewed below, including our recent evidence on the significance of some of these relations.

Smolt Size and Age

Usually the older sockeye smolts and the largest in each age-group migrate first in the spring (Foerster, 1937; Barnaby, 1944; and Krogius and Krokhin, 1948). Thorsteinson and Roos (MS, 1958) found at Chignik Lake that the largest smolts migrated earliest in the season and earliest in the evening. Burgner (1962) observed at Lake Aleknagik that the largest smolts also migrated first in the evening, and O. E. Kerns (personal communication) reported that at Iliamna Lake the oldest smolts migrated earliest in the season and earliest in the evening.

Migration Stimulation

Time of ice breakup, spring overturn, and warming of the water are related to the amount of solar radiation and the thickness of the ice cover. The start of smolt migrations has been related to time of ice breakup for Lake Aleknagik (Burgner, 1962), for Iliamna Lake (Kerns, 1961), and for Kitoi Lake (Parker and Vincent, 1956). However, the shift in young sockeye from a nonmigratory to a migratory stage of their life cycle may be related strongly to photoperiodism. So the timing of migration may not deviate as much from calendar dates as it would were it strongly related only to climatic conditions.

In lakes that do not freeze over, the migration stimulus still appears to relate strongly to rising spring water temperatures. Foerster (1937) found that migration began at Cultus Lake as temperatures rose past 40 F. In 1934 the minimum winter water temperatures did not drop below 41 F, however, and yet the smolts did not migrate before early spring; in 1936 winter water temperatures fell as low as 37 F (March 2) yet migration occurred about the same time as in 1934. So, although slight increases in water temperatures in mid-March some years were followed by initiation of smolt migrations, the migrations also occurred in other years lacking the thermal stimulus immediately before the migrations, and we must again turn to photoperiodism as the overriding stimulus or releaser.

Thermal Range

During 6 years of observations at Brooks Lake and 3 years at Karluk Lake, we found that smolt migrations began in strength as spring water temperatures rose above 40 F and were essentially over as temperatures rose past 46 F. Sudden decreases in water temperatures would be accompanied by lulls in the migration, after which sudden increases in temperatures would correspond with surges in the migration. These general phenomena are illustrated in data from Brooks Lake (Fig. 22) for 1961.

Water temperature ranges within which most smolt migrate are not materially different in other areas. In Cultus Lake (Foerster, 1937) and Lake Aleknagik (Burgner, 1962), spring smolt migrations started as lake water temperatures rose above 40 F and stopped as they rose above 49 F. Parker and Vincent (1956) found the temperature range for migration at Kitoi Lake to be 40–55 F. At Chilko Lake in British Columbia migrations started at about 38 F and were nearly over when temperatures reached 45 F (Harvey, 1963). Jaenicke (MS, 1963) found that most smolts left Ugashik Lake when water temperature ranged between 39 and 46 F.

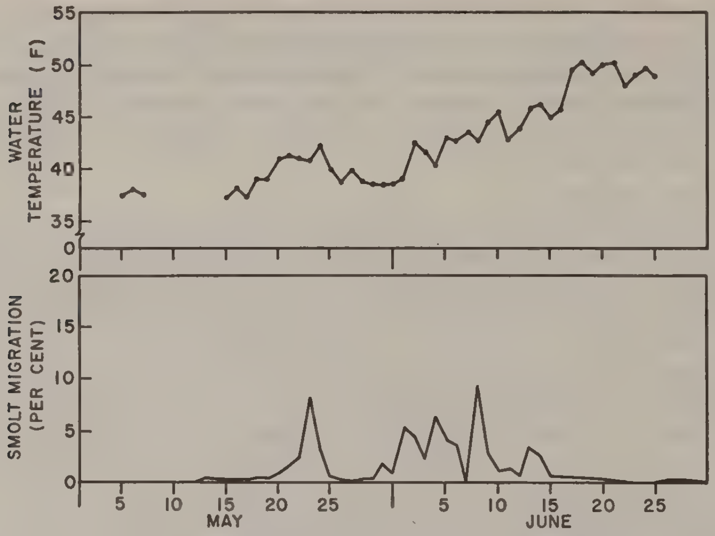


FIG. 22. Mean water temperatures and percentage of the season's total smolt migration from Brooks Lake on different dates between May 5 and June 28, 1961.

OTHER FACTORS

Varying wind, cloud cover, rainfall, and water levels have been suggested as causing fluctuations in the intensity of migration. Thorsteinson and Roos (MS, 1958) noted that smolt catches in Chignik River were small when winds were offshore at the lake outlet, but large when winds were onshore. Jaenicke (MS, 1963) also observed this phenomenon at Ugashik and Becharof lakes. At Karluk Lake, too, wind onshore at the outlet usually was coincident with large outmigrations.

A number of factors may be operating when the wind is onshore. Surface currents move onshore, and warmer surface waters may "pile up" at the outlet; as a result, temperature in the outlet stream may rise slightly, and turbidity usually increases. It is not known which of these factors affect the intensity of migration. Hartman et al. (MS, 1961) found that a strong onshore wind at Brooks Lake not only greatly accelerated the intensity of the smolt migration but also greatly altered the horizontal distribution of smolts in Brooks River below the lake outlet. Smolts were concentrated in an onshore current of turbid water caused by the direction of the wind in relation to the location of the outlet. Smolts remained in the turbid band of water in the river for a sufficient distance to materially alter the pattern of catches in fyke nets 100 yards downstream from the lake.

Considering factors other than wind, Foerster (1937) observed at Cultus Lake that daily smolt migrations increased after warm bright days and decreased after cool dull days.

BEHAVIOR OF MIGRATING SMOLTS

Our underwater observations on smolt behavior were made with three questions in mind. Do smolts migrate individually or in schools? At what water depth do smolts migrate? Are smolts passively displaced downstream during migration, or do they usually migrate facing downstream and actively swimming?

SCHOOL BEHAVIOR

Observations at several locations revealed that sockeye smolts schooled during migration. At Brooks River, only 15 smolts were seen migrating individually, whereas 25 schools of 2–10 smolts, 22 schools of 11–100, and 20–30 schools of more than 100 smolts were seen migrating. On two occasions in 1962 at Karluk many schools of 400–800 migrating smolts were seen. In 1963 at Karluk Lake, the size of schools ranged from 25 to 300 (eight observations). During extremely heavy migrations in 1962 at Naknek River, thousands of smolts were observed migrating in a continuous band. Very possibly these schools were so close together that they coalesced. The size of schools of sockeye smolts at Lakelse Lake usually varied between 20 and 200 (Brett and Alderdice, 1958).

Underwater observations at Karluk and Brooks Lakes indicated that smolts are schooled in the lake near the outlets. Other observers have reported smolts schooled as they approach lake outlets at the time of migration, e.g. Foerster and Ricker (1953) at Cultus Lake, Burgner (1962) at Lake Aleknagik, Johnson and Groot (1963) at Babine Lake, R. L. Wallace (personal communication) at Coville Lake, and C. J. DiCostanzo (personal communication) at Ualik and Ugashik lakes.

Migrating schools of smolts approaching Brooks Lake outlet generally have an ovoid shape. As the school enters fast current in the outlet (2–4 ft/sec), it becomes elongated and narrower. Surface "bow waves" from ovoid schools of young-of-the-year migrants leaving Coville Lake were observed by us on calm days throughout August 1962.

DEPTH OF TRAVEL

In the clear-water rivers draining Brooks and Coville Lakes, sockeye smolts migrate in the upper layer of water. In 37 schools of smolts migrating from Brooks Lake (Fig. 23), most smolts were in the top 20% of water depth and none were in the bottom 20%. Most smolts in the top tenth of the water column were at least several inches from the surface. Two small schools were observed in the 0–20% range in the outlet to Coville Lake, where the water averaged 6.5 ft deep. In the outlet to Naknek Lake, a steady stream of migrating smolts was seen between 2.5 and 3.5 ft (stream depth slightly more than 5 ft), or in the layer of water between 50 and 75% of the distance from the surface. O. E. Kerns (personal communication) has observed that smolts migrate in Kvichak River near the surface during darkness and near the bottom in the deepest channels during daylight.

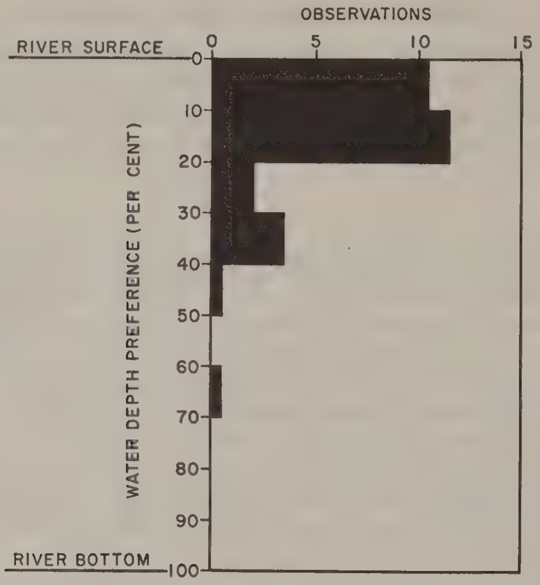


FIG. 23. Sockeye smolt schools migrating at different water depths in the outlet of Brooks Lake, 1961–63. Average depth of each school is plotted in the appropriate tenth of the distance from the surface to the bottom. The figure is based on observations of 37 schools representing several thousand smolts.

These observations seem to agree with Stuart's (1962) findings on the importance of visual contact with stream bottoms to migrating salmonid smolts. He demonstrated experimentally that the fish strive to remain at a certain relevant distance from the bottom, depending on turbidity and fish size. This distance is shortened by increased turbidity and extended by increased fish size. Thus, in the deeper more turbid streams, such as Naknek River, smolts would be relatively farther from the surface than in the shallower clear streams like the outlet to Brooks Lake. Although smolts moving toward the outlet of Karluk Lake in 1962 and 1963 were in schools at depths between 10 inches and 7 ft, definite preference for the littoral shallow areas was obvious.

A series of observations at the outlet of Coville River on August 20, 1962, may bear on the role of visual contact with the stream bottom during migration. A steady procession of schools of young-of-the-year sockeye was observed approaching the lake outlet along the northeast shoreline between 1500 and 1700 hr. Bow waves of these schools could be seen easily on the calm surface by an observer on shore. At the point where these schools passed from the lake into the river, the depth increases sharply from less than 2 ft to about 5 ft. Underwater observations indicated that as schools swam downstream over this drop-off, the fish momentarily reoriented themselves and faced upstream into the current before turning downstream again and continuing their migration. The same behavior was observed in several schools; possibly this sudden reorientation was a result of momentary loss of visual contact with the bottom.

Active vs. Passive Migration

Migrating smolts generally swim downstream actively. Large numbers of smolts seen entering the outlet of Karluk Lake were oriented facing downstream and swimming faster than the current. In Brooks River, Coville Lake outlet, and Naknek River, nearly all smolts observed were facing downstream.

Under certain natural conditions, however, passive displacement downstream has been observed. Foerster (1929) noted continuous passive downstream drift of yearling smolts in the outlet of Cultus Lake. He contrasted this behavior with that of migrating fry that speed singly and rapidly downstream, headfirst. Barnaby (1944) also observed in Karluk River that smolts headed upstream when migrating in areas with appreciable current. On the other hand, Hoar (1953) found in studies in experimental tanks that yearling smolts experiencing a small but sudden elevation in temperature often swam vigorously and rapidly with the current.

Other observations of smolts being passively displaced downstream were attributed to unusual influences such as nets, lights, and falls. In Brooks River, smolts swimming downstream immediately faced upstream upon entering the wings of fyke nets. They maintained their position briefly before the current of 3–4 ft/sec carried them into the net. During darkness when the narrow beam of an underwater hand lamp was directed across Brooks River at right angles to the current, downstream migrating smolts passed quickly through the beam with no change in rheotactic response. When the light was directed obliquely upstream and held on an individual smolt for 1–2 sec, the smolts usually reoriented upstream and passively drifted from view. Smolts observed below Brooks River Falls were tumbled about in the fall pool before they apparently drifted passively downstream. Most smolts observed 30 yards below these falls were oriented downstream. In the shallow area just below Karluk Lake and immediately above a weir used for counting adult sockeye, most smolts were oriented into or across the current and were carried downstream by it. Only 100 yards above this weir in the outlet, smolts were usually actively swimming with the current. It is possible that this aberrant behavior was caused by visual and rheotactic responses of smolts to the weir, which crossed the river. R. Straty (personal communication) noted for several years at the Naknek River adult salmon-counting weir that schools of smolts held above the weir for some time before passing through it. The fish faced upstream as the school moved back and forth across the river immediately above the weir.

There is convincing evidence that smolts also migrate actively through lakes on their way to the outlet rivers. Smolts migrating down the Babine Lake basin complex in spring moved more rapidly than water currents and averaged 3.2 miles per day in 1960 and 4.9 miles in 1961 (Johnson and Groot, 1963). Burgner (1962) estimated the average rate of travel of a marked smolt at 4–5 miles per day in the Wood River system. These travel rates greatly exceed downlake water currents in either system. Field observations by Groot (1965) at Babine Lake show that within the lake, seaward migration is "...a well-oriented movement on a rather direct route from all parts of the lake to the outlet." Groot also discovered experimentally that sockeye smolts probably have more than one direction-finding system for locating the outlet. In fact, he postulates three systems: (1) sun-compass; (2) polarized light cues; and (3) an unknown noncelestial system called type-X compass orientation.

PREDATION ON MIGRATING FRY AND SMOLTS

The most important freshwater fish predators on juvenile sockeye in southwestern Alaska are Dolly Varden (*Salvelinus malma*), Arctic char (*Salvelinus alpinus*), rainbow trout (*Salmo gairdneri*), and lake trout (*Salvelinus namaycush*).

Various birds also feed intensively on smolts, especially as the fish are leaving the lakes and entering the outlets. The Arctic Tern (*Sterna paradisaea*) and Glaucous-winged Gulls (*Larus glaucescens*) are the most common avian predators mentioned by Thompson et al. (MS, 1964). R. L. Burgner (personal communication) observed the Bonaparte's Gull (*Larus philadelphia*) to be as active a predator as the Arctic Tern at Lake Aleknagik outlet, Agulowak River, and Little Togiak River in the Wood River system. The simultaneous predation on sockeye smolts by fish from beneath and birds from above is readily observed along migration pathways. Often the activity of fish predators will cause the water to boil during migration of smolts around such areas as the outlets of Coville Lake, Grosvenor Lake (R. L. Wallace, personal communication), Naknek Lake (H. W. Jaenicke, personal communication), and Lake Amanka (C. J. DiCostanzo, personal communication).

Extensive predation on sockeye fry has been reported at Chignik Lake, Alaska, by Bower (1929) and Roos (1959, 1960); in lakes in Kamchatka by Semko (1956); and at Hidden Creek by Hartman et al. (1962). Foerster (1938) noted that heavy fish predation on smolts occurs at Cultus Lake. Ricker (1954) considered it likely that predation on downstream-migrating salmon is an example of mortality that Neave (1955) calls depensatory, where predators of a given abundance take a fixed number of prey during the time of contact, independent of the abundance of prey. Thus the smaller annual fry or smolt populations would experience a greater percentage mortality than the larger populations. This phenomenon recently has been considered to play a major role in causing and maintaining the strong cyclic dominance of certain brood-year strains of Fraser River sockeye (Ward and Larkin, 1964).

Mortality of migrating smolts may also be severe in certain rivers. Smolts leaving Kulik, Beverley, and Nerka lakes in the Wood River system must pass through the 4-mile-long Agulowak River into Lake Aleknagik. Thompson et al. (MS, 1964) found a large concentration of Arctic char in Lake Aleknagik around the outlet of the Agulowak River during the spring smolt migration period of 1954. They estimated the population size of the char by tag-and-recapture techniques; determined stomach contents and considered digestion rates; and estimated that about 1,300,000 smolts were eaten by the char assembled there. Translated into terms of returning adults, and assuming a conservative average of 15% marine survival, this represents a loss of 195,000 adults returning to the fishery and spawning grounds.

Arctic char are abundant in and around other lake-connecting rivers in the Wood River system. Aspinwall (1963) observed them in Little Togiak River feeding heavily during the night on smolts. One char captured contained 16 sockeye smolts in its stomach.

When sockeye smolts leave Karluk Lake, sizable schools of Dolly Varden congregate in the lake outlet. Heavy predation by these char on the smolts has been observed night after night.

Lake trout also prey on smolts migrating through some rivers that connect lakes. Lake trout actively feed on sockeye smolts in the Narrows between Nuyakuk and Tikchik Lakes in the Wood River system (R. L. Burgner, personal communication). At Coville Lake, on May 27, 1963, the stomachs of seven of nine lake trout caught at the outlet contained smolts. The number of smolts per stomach ranged from 23 to 41 (average, 32).

Another factor that affects different smolt populations disproportionately is the length and nature of the travel route through single-lake or multilake systems. Smolts leaving Coville Lake in the Naknek River system pass through its outlet, then the outlet of Grosvenor Lake, and finally the trunk river outlet from Naknek lake (Fig. 1). They are vulnerable to predation in all three outlets. In the Wood River system, smolts from Lake Kulik have to negotiate four lake outlets to reach salt water, whereas smolts from the lowest lake in the system, Lake Aleknagik, have to pass through only one (Fig. 1). Predation on smolts occurs in each of the four outlets in the Wood River system according to R. L. Burgner (personal communication). If predation on smolts is an important limiting factor in determining size of adult populations, are there mechanisms in the biotic potential of lower and upper lake populations such as differences in fish size, fecundity, or age at maturity, that compensate for the differences in the total length of streams that migrating smolts must pass through ? Data are not yet available to evaluate these factors, although Ricker (1966) discusses the possibility of a depensatory relation between smolts of different stocks migrating through a common trunk stream.

MIGRATORY HABITS AND SURVIVAL

TIME OF MIGRATION AND SURVIVAL

Most fry and smolts migrate when environmental opportunities in the lakes and oceans are most favorable for their survival and growth. Early spring migrations of fry coincide with the start of the growing season in the lakes, when water temperatures rise, plankton blooms, and the rate of growth of fish increases (fry become less vulnerable to predation as they increase in size). Foerster (1938) reported that mortality of young-of-the-year sockeye at Cultus Lake declined rapidly as the first growing season progressed. The early spring migrations of most smolt populations to salt water also coincide with the start of the growing season. A further possible advantage of migration in early spring is that food needs of piscivorous predators may be minimal because of the cold water temperatures.

Exceptions to this apparently propitious seasonal timing of migration occur. Spawning occurs in both summer and fall in Meadow and Canyon creeks at Karluk Lake. Fry from summer spawners emerge and migrate into Karluk Lake in April; fry from fall spawners emerge and migrate in late June and early July. These late-migrating fry miss the first part of the growing season. They are undoubtedly smaller throughout the summer than early spring migrants and may well be at a survival disadvantage in the face of predation, especially over the long winter period. Compensatory mechanisms are likely to be operating in this instance. If fall spawners are more fecund than spring spawners, this could well be an adaptive response by the fall spawning population to a higher mortality, as Nikolsky (1963, p. 152–153) might suggest.

Behavior and Survival

Predation has been shown to be a serious cause of freshwater mortality of migrating sockeye fry and smolts at certain times, especially when the smolts leave the lakes and are confined to rivers along the migration route. The migratory behavior of these juvenile sockeye seems to be adapted to minimize the mortality from predators.

We do not want to overemphasize predation as a major mortality factor on sockeye survival. Tremendous losses in freshwater are related to many other biological, physical, and chemical factors. Yet, in the migratory phase of life history for fry and smolts, predation must be extremely critical to survival.

The usual schooling of smolts would seem to promote survival in at least two ways. The incidence of contact between predator and prey is probably reduced, especially during open-lake migration, because prey are grouped at specific points rather than distributed generally. Probably the function of the school after predators have made contact is of greater importance. The school may present a more formidable aspect to predators than randomly distributed individuals. Unfortunately, few observations have been recorded on the behavior of prey under attack by predators. Whether schooling of certain prey species is advantageous in reducing losses to predators in certain situations is still mostly conjecture.

The theoretical problem involved in sending unescorted ships across the ocean, subject to discovery by enemy submarines, is similar to this problem. The basic theory was published by Koopman (1956) and adapted to fish schooling and predation by Brock and Riffenburgh (1959). Olson (1964) presented a simple example illustrating that the probability of a small fish being eaten when swimming alone was substantially higher than if it were in a school.

Rapid travel through outlet streams during the darkest hours also must enhance greatly the chances of survival of both fry and smolts. Downstream migrations of smolts are mainly confined to the darkest hours of the night, when the chances of visual perception by predators may be at a minimum. The downstream orientation during migration of fry in certain streams and of smolts in most, if not all, rivers should aid more effectively than passive downstream displacement would in the detection of potential predators and allow greater opportunity for escape; swimming with the current also helps to minimize the period of exposure to predation.

PATTERNS OF JUVENILE MIGRATORY BEHAVIOR

Sufficient data are now available to outline the broad scheme of behavior with regard to phototaxis, rheotaxis, and schooling of sockeye from fry to smolts. The general pattern during the spring emergence of sockeye fry from the gravel in tributaries leading into lakes is one of negative phototaxis, restricting migration almost completely to the darkest hours of the night. Fry migrate individually, are negatively rheotactic, face downstream during migration, and swim actively. Fry emerging directly into the lakes from lake beach spawning areas presumably quickly adopt the behavior of lake residents described below.

Shortly after fry enter the nursery lake or after extensive holding en route, schooling takes place; and it continues to some extent at least during the remainder of their residence in the nursery lakes. A sharp change from negative phototaxis accompanies or is an immediate prerequisite to schooling — a behavior which is strongly related to visual stimuli and feeding (Hoar, 1956; McDonald, 1960). Their phototactic behavior during this period is neither strictly negative nor positive. Some young-of-the-year at Karluk Lake are normally present in very shallow littoral areas during daylight in June and July. Some young sockeye remain in Brooks River well into late summer and actively school and feed during the daylight. Young sockeye in open-lake waters however are to some extent negatively phototactic. They are found at or near the surface at night and usually much deeper during daylight (Johnson, 1958; Pella, 1964). Pella presents Lake Aleknagik survey echograms taken periodically over 24-hr periods. The ascent of young sockeye to the surface at dusk and their descent to deeper depths at dawn are dramatically evident in the echograms.

The limited observations reported suggest that they are now positively rheotactic, a behavior mechanism that could be a major factor in confining juvenile sockeye to the lakes during the rearing period (Hartman et al., 1962). This conclusion was strengthened by observations on three releases of fry in the current at the outlet of Brooks Lake in 1964. Each school of 30–50 fry was followed underwater by divers, and was seen to move directly and constantly upcurrent into the lake proper. Attempts to block and panic the fry only momentarily disrupted their upstream movements, which were resumed when the diver moved away to the limit of visual contact by the diver with the fry.

Sockeye smolts are schooled as they migrate to the sea. Groot (1965) found them well oriented, schooled, and actively migrating, most especially at night in Babine Lake. In the rivers, they continue the greatest activity at night, are generally negatively rheotactic, and actively swim downstream with the current. The fry and smolts migrating downstream differ only in their schooling behavior: fry are usually unschooled, smolts are usually schooled. In some British Columbia rivers, smolts under total darkness apparently become unschooled and migrate as individuals until daylight when schooling again occurs (Howard Smith, personal communication). In Bristol Bay, however, total light extinction seldom occurs during nocturnal migrations in late May and early June, as evidenced by photometer readings at Brooks Lake. Schooling of smolts seems more persistent there throughout nocturnal migrations.

Several complicated exceptions to this general scheme, especially for fry migrations, indicate the spectrum of behavioral response to different environmental conditions. Normally, after short downstream migrations from natal tributaries, sockeye fry school when they first reach the lakes. In some instances where downstream migration requires 2 or 3 days of travel, sockeye fry tend to school during daylight holding periods (McDonald, 1960) and probably remain schooled thereafter. Rheotactic response sometimes shifts briefly from negative to positive among both migrating fry and smolts, and migration continues by passive displacement downstream. This shift may be associated with loss of relevant visual contact with river bottoms as suggested by Stuart (1962), especially in deep rivers or large pools. Upstream migrations of fry from spawning areas in lake outlets such as at Lake Chilko (Andrew and Geen, 1960) and Karluk Lake occur several days, if not weeks, after emergence. These fry, at Karluk at least, are usually schooled and migrate during daylight along the river banks (Robert F. Raleigh, personal communication). There are, however, even more complicated situations than these. Andrew and Geen (1960) report the "Sockeye fry produced by spawning in the South Thompson River below Little Shuswap Lake (Fraser River system) pass upstream through this lake and, after swimming upstream through Little River, enter Shuswap Lake (their usual rearing area)." And finally an extremely complicated fry behavior is reported by Ricker (1966). He notes that at Morris Creek in British Columbia, emerged sockeye fry "... first go downstream, then swim through a few hundred meters of practically slack water, then turn upstream into the Harrison River at the head of the rapids and proceed into Harrison Lake."

While this paper was in final editorial review, P. McCart published his fine paper on the behavior and ecology of sockeye salmon fry in the Babine

River (McCart, 1967). His observations on downstream and upstream fry migration behavior strongly support our main conclusions, and he has added considerable detail to our knowledge of upstream fry migrations.

ACKNOWLEDGMENTS

Mr Herbert W. Jaenicke of the Auke Bay Biological Laboratory has been field supervisor of research on sockeye smolts at Naknek, Becharof, and Ugashik lakes since 1959. We wish to acknowledge his generous contribution of unpublished data, his detailed analyses of some of the data for us, and his review of the manuscript. We also acknowledge for review of the manuscript Dr Charles J. DiCostanzo of the Auke Bay Biological Laboratory; Dr Robert L. Burgner, Dr Ole Mathisen, and Mr Orra E. Kerns, Jr., of the University of Washington; and Dr R. E. Foerster of the Fisheries Research Board of Canada, Biological Station, Nanaimo, British Columbia.

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Length-Weight Relation of the Sea Scallop, *Placopecten magellanicus* (Gmelin)

BY EVAN B. HAYNES[1]

Abstract

The relationship between length of shell and weight of adductor muscle of sea scallops was determined from scallops collected at Georges Bank, Cape Cod Bay, Stellwagen Bank, the inshore waters of Maine, and off Block Island. Weights of the muscle for a given shell length were practically the same for males and females. Differences of the length-weight relation were significant between scallops collected in different seasons from Georges Bank. Scallops from Cape Cod Bay, Maine, and Block Island appear to differ significantly in their length-weight relations from those of Georges Bank. Meat weights of the adductor muscles of scallops from Canadian waters usually are somewhat less for a given shell length than those of scallops from the areas studied in this paper.

Introduction

Since 1949, biologists of the Bureau of Commercial Fisheries have been accumulating length-weight data on the sea scallop, *Placopecten magellanicus* (Gmelin). The samples were collected from Maine to Rhode Island on commercial scallop boats, chartered vessels, and research vessels; most samples were from Georges Bank off Massachusetts (Fig. 1). Although the samples were collected over several years, most are from 1961 and 1962.

The objectives of this paper are (1) to determine if differences exist in the length-weight relation of the sea scallop between sexes, by state of gonads, and in various areas of the fishery, and (2) to provide a set of estimating equations.

The weights in this paper are those of the adductor muscle of the sea scallop (Fig. 2). This is the only part of the animal retained by the fishermen; the rest of the viscera and the shell are discarded at sea. The muscle usually makes up about 10–15% of the total weight of the scallop and about 30% of the viscera. Fishermen shucking the scallops at sea usually leave 2–10% of meat attached to the shell. We attempted to duplicate commercial practice and estimate that we lost about 3%. Each shucked scallop meat was weighed to an accuracy of ± 0.03 g. Length, here defined as the greatest distance between the umbo and the shell margin (Fig. 2), was measured to the nearest millimeter.

The sexes are separate in the sea scallop and, in mature individuals, are easily identified: in males, the gonad (Fig. 2) is creamy white and in females is bright red. Identification of the sexes is difficult or impossible immediately after spawning and for immature scallops.

Less than 0.7% of the scallops used in this study were immature (smaller than 50 mm), so the results are applicable only to adults. All scallops were live or fresh. Studies of all samples, excluding those from Maine which were examined at their port of landing, were conducted at the Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts.

The statistical analyses in this study are based on 8,868 measurements, and consist primarily of the comparison of length-weight relation by the analysis of covariance. Description of the samples, including the regression constants of the logarithmic equation $\log_e W = a + b \log_e L$ are shown in Table 1. Length-weight distributions for the major fishing areas and each season considered in this study are shown in Table 2. An IBM type 7090 computer was programmed to calculate the length-weight regression for each sample by date, location, and sex. Individual meat weights and measurements of shell length were used as point values in the calculations. Length-weight comparisons were then made, between sexes, according to state of gonads, and among the various fishing grounds of Georges Bank, the inshore waters of the Gulf of Maine, and off Block Island. Too few samples were collected in certain years to permit study of year-to-year variation in the length-weight relation. The annual data have not, therefore,

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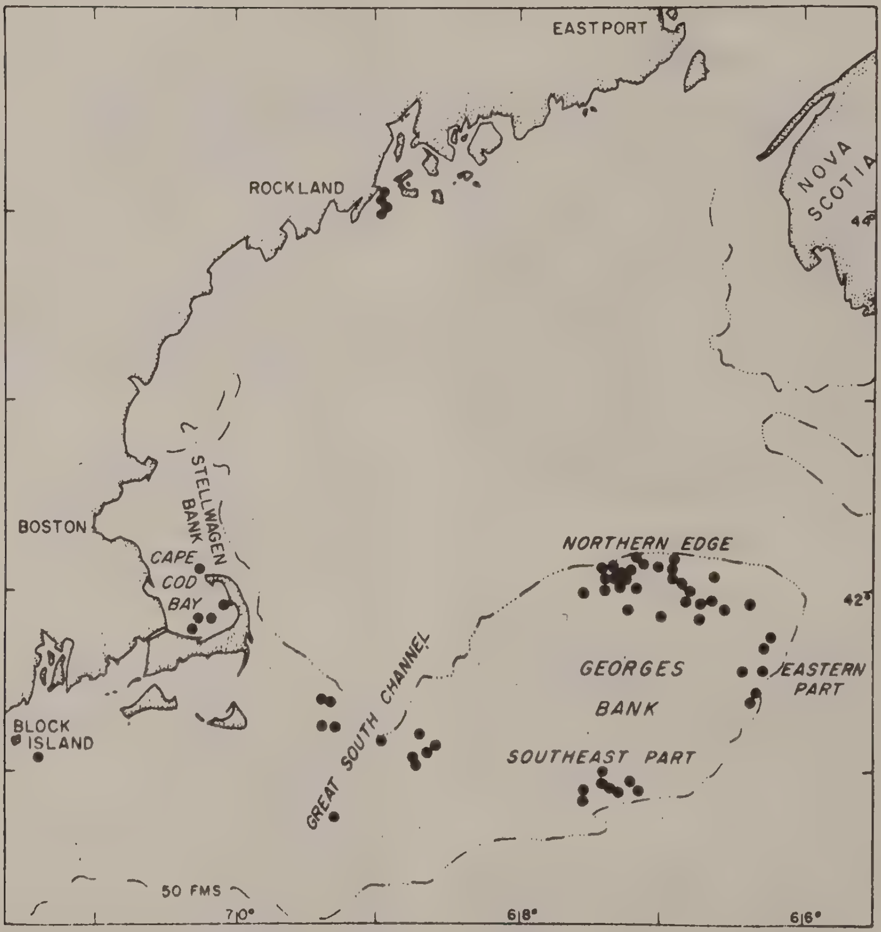
EASTPORT
ROCKLAND
NOVA SCOTIA
44°
BOSTON
STELLWAGEN BANK
CAPE COD BAY
BLOCK ISLAND
NORTHERN EDGE
42°
GEORGES BANK
EASTERN PART
SOUTHEAST PART
GREAT SOUTH CHANNEL
50 FMS
70°
68°
66°

Fig. 1. Location of the samples used in this study.

been separated. Statistical methods and terminology follow those of Snedecor (1956).

Differences Between Sexes

The first analysis was made to determine if the length-weight relations of male and female scallops differed significantly. Data were available for 3,319 males and 3,002 females. Samples which included sex information were pooled by sex and the following regressions calculated:

Males: $\log_e W = -10.0234 + 2.996 \log_e L$

Females: $\log_e W = -10.0529 + 3.003 \log_e L$

The analysis of covariance showed that differences between sexes in the slope and adjusted mean weights were not significant. The data on males and females were therefore combined in all subsequent analyses.

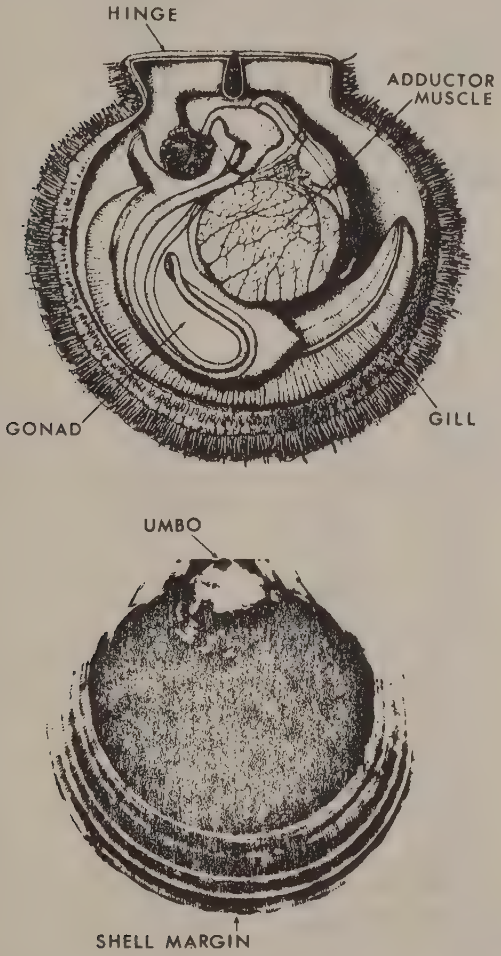

Fig. 2. Mantle cavity of the sea scallop as seen from the left side after removal of the left mantle lobe. Also shown is outer surface of the left valve.

Differences by Seasons and Areas

Georges Bank

Unpublished data on file at this Laboratory show that for each of the fishing grounds studied in this paper, spawning of scallops usually begins in late September and is completed in October. Recovery of the gonads begins in November and continues through March. From April through most of September the gonads are full and plump. Consequently, October was designated the spawning season, November through March the ripening season, and April through September the season of maturity. For ease of identification the seasons were designated S, R, and M respectively.

To detect possible seasonal trends in slope, the values for each sample were plotted against the months in which the sample was taken (Fig. 3). Since the greatest numbers of collections were made during seasons R and M on Georges Bank (Table 3) the study was restricted to these samples. The sample-to-sample variation was large but no trend is apparent for the slope values of those samples within a season.

The tests for seasonal differences in the length-weight relation of the sea scallop were based only on samples collected from the four geographical areas of Georges Bank (Table 3). As a convenience the areas of Georges Bank were designated as the Northern Edge, Eastern Part, Southeast Part, and the Great South Channel (Fig. 1).

Highly significant differences were frequent between samples within each area and season. Therefore, for each of the areas of Georges Bank a pooled mean square for differences between samples was formed for testing seasonal differences. The ratio of the estimated mean square differences between seasons to the pooled mean square differences between samples indicated whether significant differences in the regression constants exist among the seasons for the particular area tested.

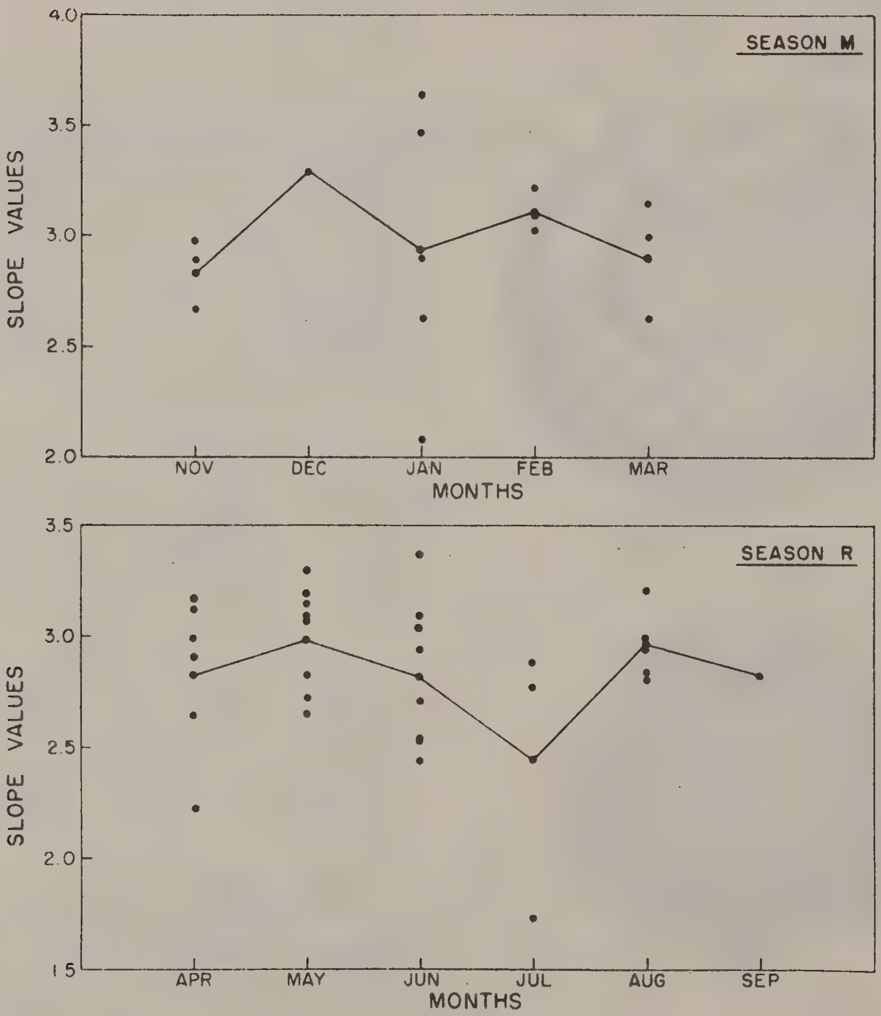

Fig. 3. Slope values plotted by month for samples taken during the ripening season, November–March (R), and season of maturity, April–September (M) on Georges Bank.

TABLE 1. Location of sampling stations, date of collection, and number of sea scallops used for length-weight analyses. The regression constants are based on the entire sample; sexes combined.

	Position			Regression constants	
Date	Lat N	Long W	Number of scallops	Slope	Intercept
			Northern Edge of Georges Bank		
1958					
May	42°05′	67°15′	222	3.063	-11.5812
1959					
Nov.	42°01′	67°12′	540	2.656	- 9.5355
1960					
Jan.	42°05′	67°21′	133	2.606	- 9.3600
Aug.	41°53′	67°14′	96	2.996	-11.1169
Oct.	41°59′	67°33′	135	2.728	- 9.8258
Oct.	42°04′	67°24′	79	2.773	-10.0407
1961					
Jan.	41°56′	66°24′	50	2.070	- 6.5203
Feb.	41°56′	66°49′	51	3.018	-11.0869
Mar.	41°59′	66°49′	59	2.599	- 8.9895
Apr.	42°08′	67°10′	85	2.223	- 7.3676
May	42°08′	66°54′	156	3.073	-11.3330
May	42°09′	67°06′	122	2.649	- 9.4276
June	42°07′	67°02′	106	2.705	- 9.7699
June	42°01′	67°24′	148	2.436	- 8.5492
Aug.	41°56′	66°42′	195	2.976	-10.8362
Aug.	41°59′	66°49′	90	2.975	-10.5112
Aug.	42°05′	66°39′	185	2.806	-10.1625
Aug.	42°06′	67°21′	74	3.198	-12.0128
Nov.	42°02′	67°17′	94	2.959	-10.9132
Dec.	42°01′	66°50′	113	3.298	-12.5065
1962					
Mar.	41°51′	66°45′	114	2.996	-11.0260
Mar.	41°56′	66°43′	71	2.892	-10.5524
Apr.	41°56′	66°42′	83	3.108	-11.5805
Apr.	42°05′	67°24′	134	2.642	- 9.3911
Apr.	42°06′	67°20′	131	2.888	-10.5242
May	41°54′	66°36′	82	2.810	- 9.9988
May	42°03′	66°57′	87	2.719	- 9.4362
June	42°07′	66°57′	104	2.934	-10.6349
June	42°03′	67°17′	98	2.526	- 8.5837
July	41°52′	67°02′	83	2.889	-10.3990
			Great South Channel		
1957					
Aug.	41°15′	69°25′	53	2.821	-10.4052
1960					
Oct.	40°46′	69°21′	40	2.429	- 8.5862
Oct.	41°10′	68°00′	130	2.646	- 9.6656
Oct.	41°23′	69°23′	122	2.622	- 9.7407
Oct.	41°22′	69°22′	107	1.287	- 3.3621
Apr.	41°07′	68°39′	115	3.143	-11.5544
Apr.	41°09′	68°37′	75	2.996	-10.8818

TABLE 1. (continued)

Date	Position		Number of scallops	Regression constants	
	Lat N	Long W		Slope	Intercept
		Great South Channel (continued)			
1961					
May	41°12′	68°43′	211	3.184	-11.7909
Sept.	41°15′	69°21′	57	2.804	-10.1032
Oct.	41°02′	68°45′	200	2.938	-10.8976
Nov.	41°04′	68°46′	96	2.878	-10.6776
		Eastern Part of Georges Bank			
1961					
Jan.	41°33′	66°26′	72	2.892	-10.5923
Feb.	41°36′	66°18′	66	3.080	-11.4674
May	41°45′	66°15′	283	3.143	-11.5670
July	41°26′	66°23′	96	1.724	- 5.1385
1962					
June	41°27′	66°22′	213	3.031	-11.1318
June	41°42′	66°17′	98	2.526	- 8.5849
		Southeast Part of Georges Bank			
1959					
Mar.	40°57′	67°25′	67	3.134	-11.7892
1961					
May	40°52′	67°34′	164	3.292	-12.2719
1962					
Jan.	40°57′	67°12′	112	3.464	-13.3898
Jan.	40°56′	67°11′	113	3.685	-14.4960
Feb.	40°55′	67°33′	107	3.212	-12.3300
June	40°55′	67°22′	147	3.078	-11.4220
June	40°55′	67°19′	46	3.364	-12.7172
July	41°01′	67°26′	136	2.765	- 9.9953
		Cape Cod Bay			
1949					
Dec.	41°55′	70°05′	101	2.965	-10.8539
1960					
Oct.	41°51′	70°12′	157	3.026	-11.0604
Oct.	41°47′	70°19′	99	2.957	-10.7354
Nov.	41°47′	70°19′	55	2.935	-10.5918
1962					
Apr.	41°49′	70°16′	43	3.225	-11.9235
		Stellwagen Bank			
1950					
Aug.	42°07′	70°16′	79	2.791	-10.0516
		Maine (Penobscot Bay)			
1960					
Jan.	44°04′	69°00′	228	3.535	-13.8370
Feb.	44°00′	69°00′	220	3.541	-13.8955

TABLE 1. (continued)

Date	Position		Number of scallops	Regression constants	
	Lat N	Long W		Slope	Intercept
	Maine (Penobscot Bay) (continued)				
1960					
Mar.	44°03′	69°00′	213	3.524	-13.7823
Apr.	44°54′	67°03′	261	2.995	-11.0317
1961					
Feb.	44°01′	69°01′	185	2.869	-10.3246
	Block Island				
1958					
May	41°05′	71°24′	138	2.320	- 8.0971
July	41°05′	71°24′	133	3.050	-11.3942
Aug.	41°05′	71°24′	149	3.071	-11.5560
Sept.	41°05′	71°24′	100	2.892	-10.8200
Dec.	41°05′	71°24′	61	3.035	- 7.0630

TABLE 2. Length-weight distributions of sea scallops for three seasons (based on state of gonads) for sea scallops from Georges Bank and the distributions for seasons combined for sea scallops from Georges Bank, Maine, Cape Cod Bay, Stellwagen Bank, and Block Island.

	Georges Bank					
	October			November-March		
Shell length	Number of scallops	Mean weight	Range	Number of scallops	Mean weight	Range
(mm)		*(g)*	*(g)*		*(g)*	*(g)*
20-24	—	—	—	—	—	—
25-29	—	—	—	—	—	—
30-34	—	—	—	—	—	—
35-39	—	—	—	—	—	—
40-44	—	—	—	—	—	—
45-49	—	—	—	—	—	—
50-54	—	—	—	—	—	—
55-59	2	3.2	3.1-3.4	—	—	—
60-64	7	3.9	3.2-4.4	—	—	—
65-69	6	5.0	4.4-5.4	2	4.9	4.7-5.2
70-74	4	6.5	6.1-7.2	12	6.2	4.8-9.6
75-79	3	7.6	6.4-8.6	18	7.4	4.4-14.4
80-84	11	9.4	7.9-10.9	48	7.8	5.1-9.5
85-89	18	11.1	6.1-13.8	45	10.1	4.7-13.6
90-94	85	11.1	8.1-15.2	145	11.3	6.2-19.5
95-99	153	12.1	8.4-18.4	440	12.6	6.6-21.2
100-104	212	13.2	8.8-23.7	443	14.6	9.4-23.6
105-109	116	15.6	9.7-23.4	290	17.4	11.2-28.8
110-114	75	17.8	13.0-27.3	129	20.5	13.3-31.3
115-119	37	22.7	15.6-29.5	64	25.3	15.6-38.6
120-124	41	25.1	18.9-34.0	72	28.9	14.3-42.9

TABLE 2. (continued)

	Georges Bank					
	October			November–March		
Shell length	Number of scallops	Mean weight	Range	Number of scallops	Mean weight	Range
(mm)		*(g)*	*(g)*		*(g)*	*(g)*
125–129	20	29.7	21.1–40.8	70	32.4	20.8–47.0
130–134	15	33.2	23.8–39.3	49	36.0	25.8–50.1
135–139	6	31.4	26.3–40.7	16	39.9	28.1–54.4
140–144	2	37.5	33.0–42.0	13	42.2	27.3–49.5
145–149	—	—	—	1	45.6	45.6
150–154	—	—	—	1	38.5	38.5
155–159	—	—	—	—	—	—
160–164	—	—	—	—	—	—
165–169	—	—	—	—	—	—

	Georges Bank					
	April–September			All months		
20–24	1	0.2	0.2	1	0.2	0.2
25–29	2	0.3	0.2–0.4	2	0.3	0.2–0.4
30–34	—	—	—	—	—	—
35–39	2	0.7	0.6–0.8	2	0.7	0.6–0.8
40–44	4	1.2	1.1–1.2	4	1.2	1.1–1.2
45–49	12	1.7	1.2–2.1	12	1.7	1.2–2.1
50–54	23	2.2	1.4–2.8	23	2.2	1.4–2.8
55–59	43	3.3	1.9–3.6	45	3.3	1.9–3.6
60–64	78	4.0	1.9–5.2	85	4.0	1.9–5.2
65–69	81	5.0	2.7–6.3	89	5.0	2.7–6.3
70–74	100	6.3	3.6–15.4	116	6.3	3.6–15.4
75–79	171	7.0	2.7–9.9	192	7.1	2.7–14.4
80–84	138	9.4	2.1–15.2	197	9.0	2.1–15.2
85–89	226	11.3	5.3–19.6	289	11.1	4.7–19.6
90–94	407	13.4	6.3–31.9	637	12.6	6.2–31.9
95–99	510	15.3	6.8–25.3	1103	12.8	6.6–25.3
100–104	546	17.3	8.7–30.0	1201	15.5	8.7–30.0
105–109	416	19.3	11.0–30.1	822	18.1	9.7–30.1
110–114	371	22.4	10.4–42.9	575	21.4	10.4–42.9
115–119	220	25.8	12.0–50.1	321	25.4	12.0–50.1
120–124	203	29.7	14.6–50.1	316	28.9	14.3–50.1
125–129	183	34.9	16.4–52.6	273	33.8	16.4–52.6
130–134	128	39.6	10.7–51.9	192	38.1	10.7–51.9
135–139	72	42.8	22.6–59.4	94	41.4	22.6–59.4
140–144	30	45.7	33.6–62.6	45	44.3	27.3–62.6
145–149	7	52.3	43.1–61.8	8	51.4	43.1–61.8
150–154	1	43.0	43.0	2	40.8	38.5–43.0
155–159	—	—	—	—	—	—
160–164	—	—	—	—	—	—
165–169	—	—	—	—	—	—

TABLE 2. (continued)

	Maine			Cape Cod Bay		
Shell length	Number of scallops	Mean weight	Range	Number of scallops	Mean weight	Range
(mm)		*(g)*	*(g)*		*(g)*	*(g)*
20–24	—	—	—	—	—	—
25–29	—	—	—	—	—	—
30–34	—	—	—	—	—	—
35–39	—	—	—	—	—	—
40–44	—	—	—	—	—	—
45–49	—	—	—	1	1.9	1.9
50–54	—	—	—	1	1.9	1.9
55–59	—	—	—	1	3.2	3.2
60–64	—	—	—	2	3.3	3.3
65–69	—	—	—	10	4.8	3.2–5.7
70–74	—	—	—	10	6.6	5.2–8.4
75–79	—	—	—	4	7.8	7.3–8.4
80–84	4	6.1	5.1–7.0	8	10.3	9.6–11.7
85–89	9	7.4	5.5–9.3	9	12.4	10.1–15.4
90–94	27	8.6	6.3–13.0	19	14.7	11.8–20.6
95–99	93	10.5	7.3–19.9	17	16.8	13.3–20.5
100–104	123	13.4	8.6–22.6	25	19.2	14.8–28.0
105–109	145	16.2	10.6–25.5	46	20.9	14.6–26.8
110–114	181	18.7	9.8–29.6	52	24.0	17.7–35.4
115–119	126	24.3	13.5–39.0	32	28.3	21.9–37.1
120–124	139	27.2	18.0–39.1	31	33.2	25.1–42.2
125–129	104	30.4	14.4–45.0	29	36.4	26.3–47.1
130–134	78	34.5	22.3–48.6	40	43.3	32.7–58.6
135–139	41	38.6	22.4–52.9	34	46.4	33.7–55.8
140–144	21	45.0	28.0–65.3	34	50.4	33.1–67.7
145–149	6	43.3	36.6–48.2	25	58.8	42.7–76.0
150–154	9	44.2	34.9–56.6	16	60.1	47.8–78.6
155–159	1	37.2	37.2	3	71.8	54.2–81.4
165–169	—	—	—	3	80.9	72.5–90.6

	Stellwagen Bank			Block Island		
20–24	—	—	—	—	—	—
25–29	—	—	—	—	—	—
30–34	—	—	—	3	1.1	1.1–2.2
35–39	—	—	—	6	1.5	1.3–1.7
40–44	—	—	—	15	1.4	1.0–2.3
45–49	—	—	—	11	1.7	1.1–6.0
50–54	—	—	—	13	1.8	1.2–2.6
55–59	—	—	—	10	3.3	1.7–6.1
60–64	—	—	—	8	2.8	1.8–3.6
65–69	—	—	—	12	2.9	2.7–5.1
70–74	—	—	—	21	4.9	4.0–6.9
75–79	—	—	—	51	6.0	4.5–11.9
80–84	1	9.6	9.6	50	7.2	5.4–8.5
85–89	1	12.7	12.7	74	8.7	6.5–18.5

TABLE 2. (continued)

	Stellwagen Bank			Block Island		
Shell length	Number of scallops	Mean weight	Range	Number of scallops	Mean weight	Range
(mm)		*(g)*	*(g)*		*(g)*	*(g)*
90–94	1	11.8	11.8	54	10.0	8.1–13.3
95–99	6	16.5	15.3–17.9	31	12.2	10.0–14.9
100–104	10	17.7	14.8–20.8	42	15.1	9.2–19.5
105–109	22	18.5	14.6–23.3	68	17.0	11.6–22.0
110–114	24	22.4	18.6–28.2	57	19.1	13.3–24.6
115–119	10	25.9	21.9–31.6	19	19.2	14.3–24.8
120–124	1	25.6	25.6	14	24.1	11.2–30.0
125–129	—	—	—	4	24.7	17.6–31.9
130–134	1	43.1	43.1	10	26.7	15.3–43.2
135–139	—	—	—	4	32.8	24.7–38.4
140–144	—	—	—	3	36.0	29.6–41.0
145–149	—	—	—	1	35.7	35.7
150–154	2	56.3	54.0–58.6	—	—	—
155–159	—	—	—	—	—	—
160–164	—	—	—	—	—	—
165–169	—	—	—	—	—	—

TABLE 3. Number of samples and specimens (in parenthesis) in each area by season.

	Georges Bank							
Season	Northern Edge	Eastern Part	Southeast Part	Great South Channel	Cape Cod Bay	Stellwagen Bank	Maine	Block Island
Oct.	2 (214)	—	—	5 (599)	2 (256)	—	—	—
Nov.–Mar.	9 (1,225)	2 (138)	4 (399)	1 (96)	2 (156)	—	4 (846)	1 (61)
Apr.–Sept.	19 (2,281)	4 (690)	4 (493)	5 (511)	1 (43)	1 (79)	1 (261)	4 (520)

Significant differences were found between seasons for all but the Eastern Part. The reason for the lack of significant differences in this area is unknown. Nevertheless, the significance of the differences between seasons in three of the four areas strongly suggest that they are real.

Similarly, differences between areas were tested within each season. None of the differences was significant.

The length-weight equations for scallops from Georges Bank, by season, are:

Season S: $\log_e W = -10.2516 + 2.785 \log_e L$ (Oct.)

Season M: $\log_e W = -11.7472 + 3.131 \log_e L$ (Nov.–Mar.)

Season R: $\log_e W = -10.9926 + 2.995 \log_e L$ (Apr.–Sept.)

Maine Coast, Cape Cod Bay, Block Island, and Stellwagen Bank

The numbers of samples from each season for each fishing area (Table 3) are too few to permit testing of the variations among all areas for each season. It is possible, nevertheless, to examine differences in meat weights between certain areas within a particular season.

The areas of Cape Cod Bay, Maine, and Block Island were tested against the Georges Bank areas to determine if the length-weight relations of sea scallops differed significantly from those of Georges Bank for a particular season. Suitable records were available for seasons S and M for Cape Cod Bay, season M for Maine, and season R for Block Island.

For both seasons tested, the length-weight relation of sea scallops from Cape Cod Bay did not differ significantly from that of scallops from Georges Bank with respect to the regression coefficient. They did differ significantly in the adjusted mean weights. Regression coefficients of sea scallops from Maine and Block Island differed significantly from those of Georges Bank. The results suggest that for the seasons tested sea scallops from Cape Cod Bay, the Maine Coast, and off Block Island possess real differences in their meat weights for a given shell length as compared with those from Georges Bank. The length-weight equations for these areas are:

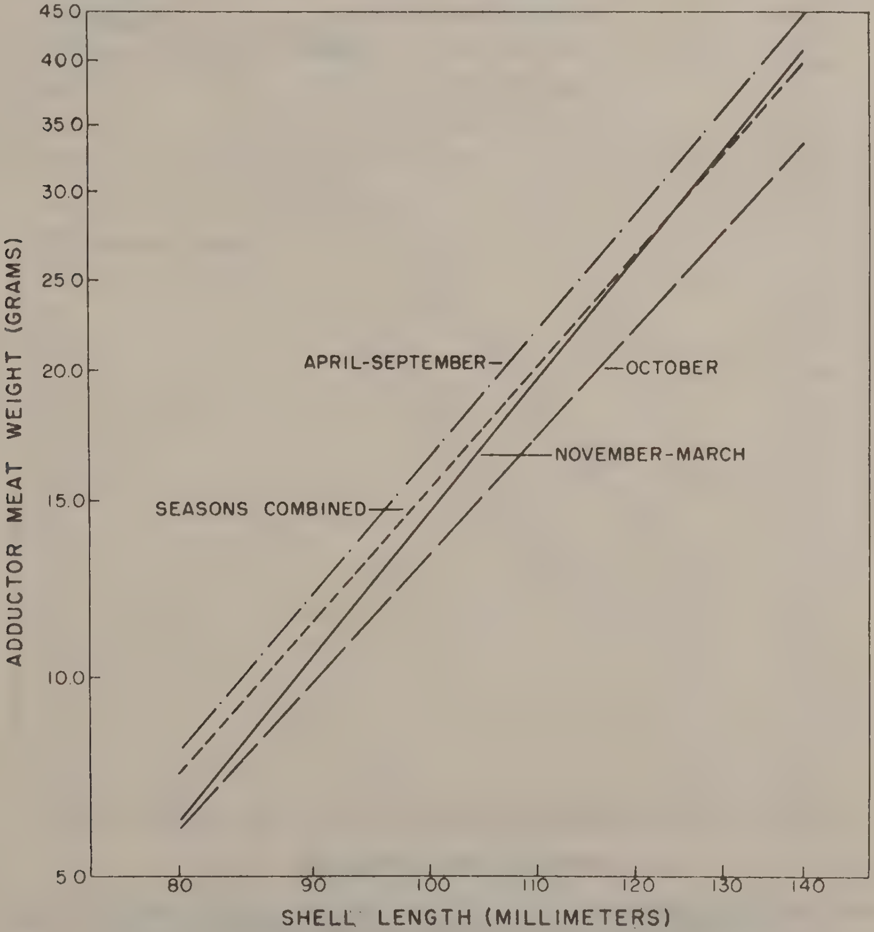

Fig. 4. Regressions of weight on shell length for three seasons (based on state of gonads) and the regression for seasons combined for sea scallops from Georges Bank.

Cape Cod Bay

Season S: $\log_e W = -10.8845 + 2.989 \log_e L$ (Oct.)

Season M: $\log_e W = -11.2666 + 3.062 \log_e L$ (Nov.–Mar.)

Maine

Season M: $\log_e W = -8.5392 + 2.427 \log_e L$ (Nov.–Mar.)

Block Island

Season R: $\log_e W = -9.7660 + 2.683 \log_e L$ (Apr.–Sept.)

The data on sea scallops from Stellwagen Bank are based on only one sample and, therefore, have not been used in any statistical tests. The regression equation is:

$$\log_e W = -10.0516 + 2.791 \log_e L$$

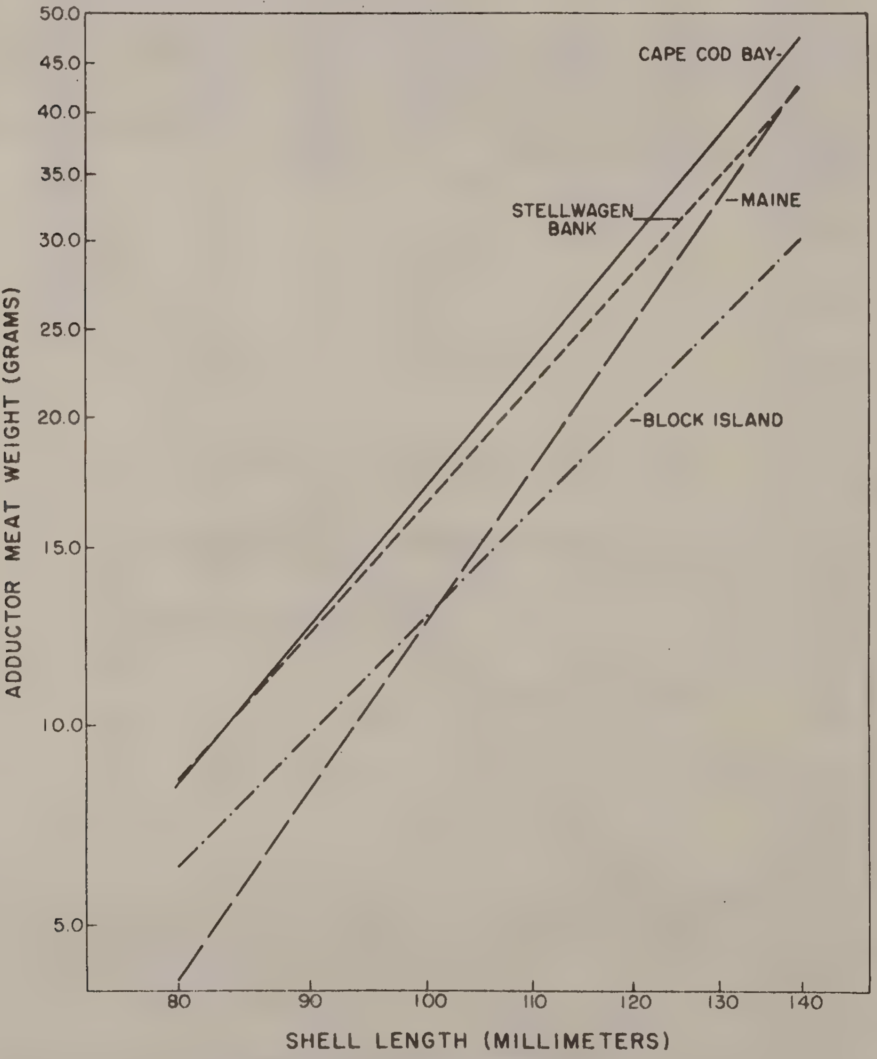

Fig. 5. Regressions of weight on shell length for sea scallops from Cape Cod Bay, Stellwagen Bank, the inshore waters of Maine, and off Block Island.

For certain purposes a single length-weight equation may be desirable for Georges Bank and also for each of the other fishing grounds considered in this paper; all samples from each area were pooled, therefore, to obtain length-weight equations. The equations are shown in Table 4; graphs of these equations appear in Fig. 4 and 5.

Ninety-five percent confidence belts were calculated for the Georges Bank regression, all seasons and areas combined (Fig. 6). The

TABLE 4. Length-weight regressions for the sea scallops taken from Georges Bank, Cape Cod Bay, Stellwagen Bank, Maine, and Block Island, data for all seasons combined.

Area	Regression equation	Number of scallops
Georges Bank	$\log_e W = -10.8421 + 2.949 \log_e L$	6,646
Cape Cod Bay	$\log_e W = -11.2441 + 3.059 \log_e L$	455
Stellwagen Bank	$\log_e W = -10.0516 + 2.791 \log_e L$	79
Block Island	$\log_e W = -9.1393 + 2.549 \log_e L$	581
Maine	$\log_e W = -14.3451 + 3.664 \log_e L$	1,107

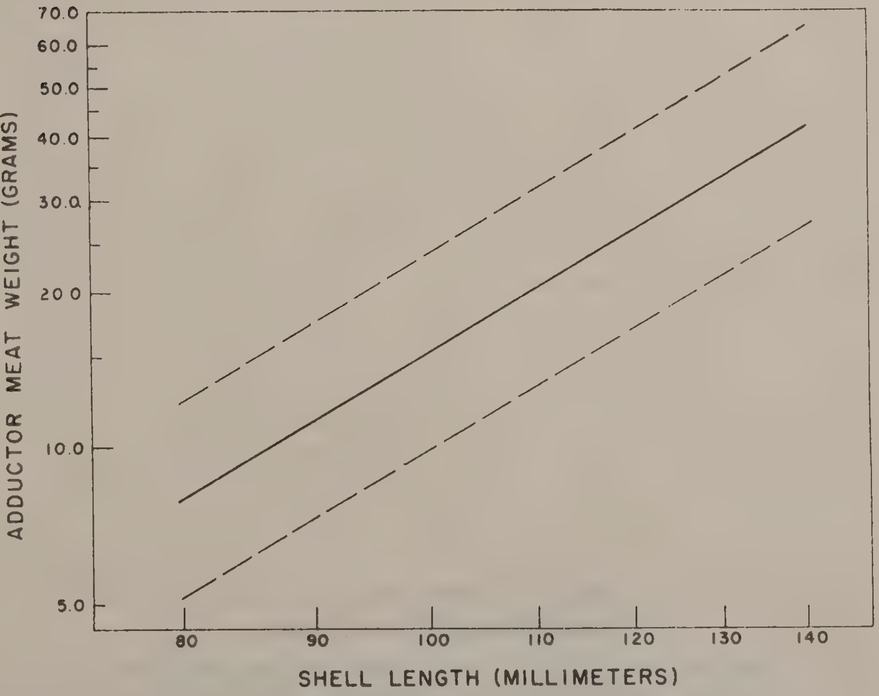

Fig. 6. Regression line for Georges Bank, all seasons and areas combined. The broken lines show the limits within which 95% of the meat weights may be expected to fall.

broken lines show the limits within which 95% of the meat weights would be expected to fall.

Figure 7 shows the expected frequency distribution of meat weights around the means corresponding to sea scallops of 95, 110, and 120 mm in shell length. The inner and outer broken lines show the limits within which 68 and 95% respectively of the meat weights would be expected to fall.

A measure of the number of organisms per unit weight is useful in studies of an exploited population. Values calculated from the length-weight regression equations for sea scallops from each fishing area and also the regression

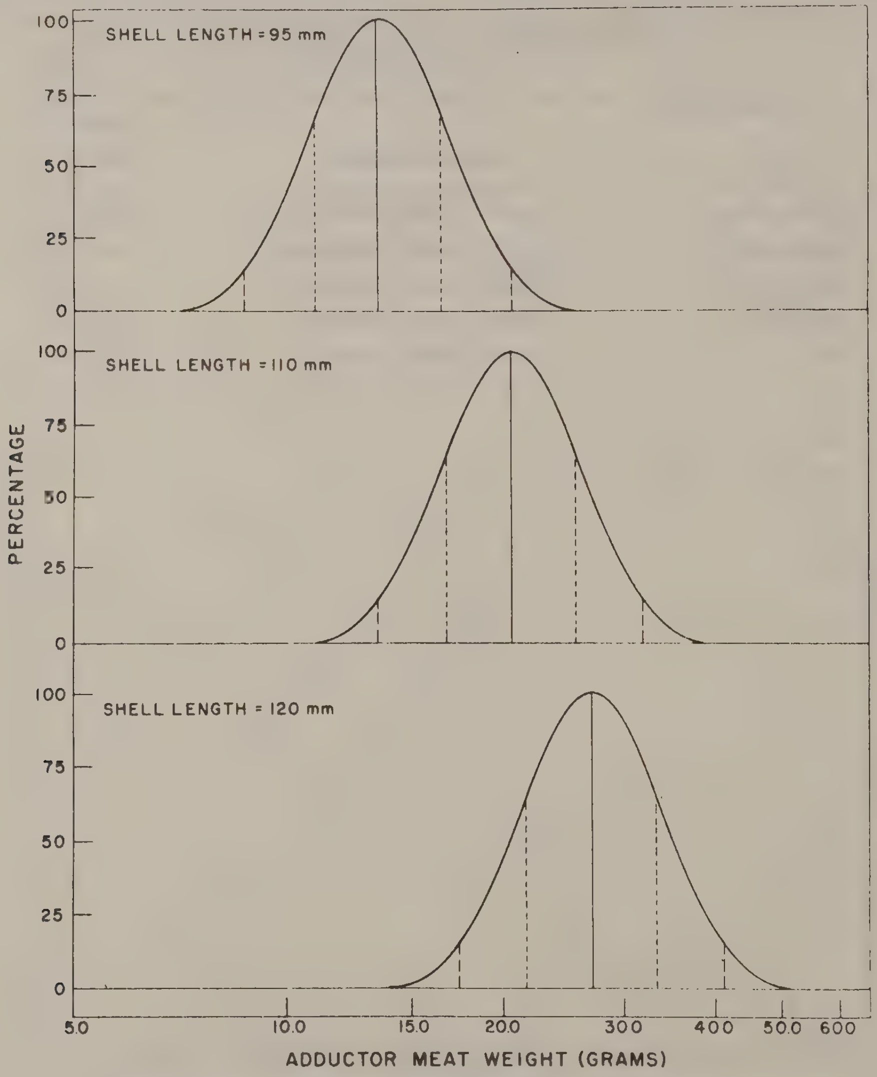

Fig. 7. Expected frequency distribution of meat weights around the means corresponding to sea scallops of 95, 110, and 120 mm in shell length. The inner and outer broken lines show the limits within which 68 and 95% respectively of the meat weights would be expected to fall.

equations for each season (in relation to state of gonads) on Georges Bank, have been used to derive the number of scallop meats per pound by 5-mm size groups from 80 to 150 mm (Table 5).

Comparison with Earlier Studies of Weights of Sea Scallop Meats

Baird (1954) published data on the length-weight relations of Maine sea scallops which differ widely from those of this study (see Fig. 8 for a comparison of the two sets of data). I fitted the line to Baird's data by eye, but disregarded the 90-mm value, which appears to be in error. Meat weights from Baird's data averaged about 32% greater than mine over the range of 80–140 mm. The locations of the sample collections differed; those of Baird came mostly from Linekin Bay, whereas mine were largely from Penobscot Bay. According to Baird, however, "The Linekin figures have since been compared with enough Penobscot figures

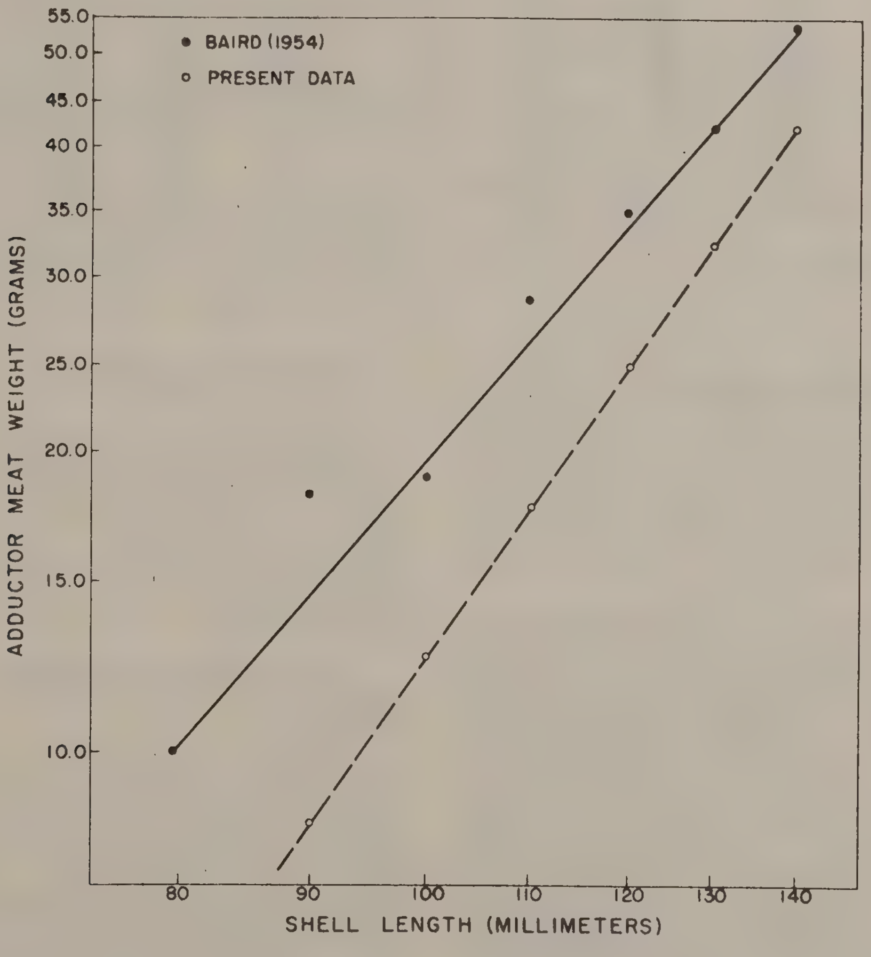

Fig. 8. Comparison of regressions of weight on length from sea scallops taken from the inshore waters of Maine.

TABLE 5. Number of meats per pound for scallops 80–150 mm long from the fishing areas of Georges Bank, Maine, Block Island, Cape Cod Bay and Stellwagen Bank.

	Georges Bank							
Shell length	Oct.	Nov.–Mar.	Apr.–Sept.	All months	Maine	Cape Cod Bay	Stellwagen Bank	Block Island
(mm)								
80–85	59.2	57.5	49.3	56.7	82.5	52.1	51.5	63.0
85–90	50.4	47.8	41.2	47.2	65.7	43.7	43.3	54.0
90–95	42.8	40.1	34.9	40.2	53.5	36.2	36.3	46.3
95–100	40.5	33.9	29.8	34.1	43.7	31.1	31.7	40.5
100–105	32.4	28.9	25.6	29.4	36.6	26.5	27.5	35.4
105–110	28.2	25.1	22.2	25.5	30.2	22.8	24.1	31.3
110–115	24.9	21.7	19.4	22.1	25.5	19.7	21.1	27.9
115–120	22.0	18.9	17.0	19.5	21.7	17.2	18.7	24.9
120–125	19.6	16.6	15.0	17.2	18.5	15.1	16.6	22.3
125–130	17.6	14.7	13.4	15.2	16.0	13.4	14.8	20.1
130–135	15.8	13.0	11.8	13.6	13.8	11.8	13.3	18.2
135–140	14.2	11.6	10.6	12.1	12.0	10.5	11.9	16.5
140–145	12.9	10.3	9.6	10.9	10.6	9.4	10.8	15.1
145–150	11.8	9.3	8.6	9.8	9.3	8.5	9.8	13.8

to convince the author that there is no significant difference in meat yield between the two areas." Also, Baird's data were apparently collected in July and August, whereas mine were taken from January to April. The seasonal differences in meat weights in this study were too small to make it likely that the total discrepancy between the two sets of data could be caused by season of collection alone.

Other data on the length-weight relation of sea scallops have been given by Posgay (1953) for Cape Cod Bay, and by Medcof (1949), and Dickie (1953) for the inshore Canadian waters (Digby area). The single regression of weight on length in this study for Cape Cod Bay is almost identical with that shown by Posgay, who used only the 1949 sample (included also in my study— Table 1). Data shown by Medcof (1949) and Dickie (1955) for the inshore Canadian waters indicate, with one exception, that the meat weights of Canadian sea scallops are generally somewhat smaller at a given length than those in the present study. The exception is the Block Island region where the adductor muscles of sea scallops weighed about 12% less than for sea scallops from Canadian waters, particularly in the larger sizes, 130–140 mm.

Summary

Samples for study of the relation between shell length and weight of the adductor muscle of the sea scallop were collected at Georges Bank, Cape Cod Bay, Stellwagen Bank, the inshore waters of Maine, and off Block Island. The samples permitted comparisons of the adductor meat weights for a given shell length between sexes, according to state of gonads, and area of collection.

Males and females had no significant differences in weights of adductor meat for a given shell length.

Analyses of length-weight data among sea scallops representing the gonad conditions of "spawning," "ripening," and "mature" were based on the samples from the Northern Edge, Eastern Part, and Southeast Part of Georges Bank, and the Great South Channel. With one exception, meat weights differed significantly among the scallops representing each gonadal state for each of the above areas. This fact strongly suggests that significant differences in meat weights for a given shell length do exist among sea scallops according to season.

Differences of meat weights among the above areas within each season were not significant.

The data were too scant for tests of the variation among all areas by season. It was possible, nevertheless, to study for certain seasons only, the differences among Cape Cod Bay, Maine, and Block Island against those of Georges Bank. For each area meat weights differed significantly from those of Georges Bank either in the regression coefficients or in the adjusted mean weights.

A pooled regression was computed from the pooled samples for each fishing ground.

The number of sea scallop meats per pound by 5-mm size groups from 80 to 150 mm are also shown for each of the fishing grounds considered in the present study.

Differences of meat weight for a given shell length were large between the data in this paper and those of Baird (1954) for the inshore waters of Maine. Although the two sets of data were collected at different seasons, it is unlikely that this difference would account for the total discrepancy.

The pooled regression of weight on length as shown in this study for Cape Cod Bay is nearly identical with that shown by Posgay (1953) who used the 1949 sample included in the present study.

Meat weights of Canadian sea scallops are generally somewhat smaller for a given length than those in the present study. An exception is offered by sea scallops from Block Island in the larger sizes of 130–140 mm, whose meat weights average about 12% less than those from Canadian waters.

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Reprinted from
MARINE BIO-ACOUSTICS
Volume 2
Proceedings of the Second Symposium on Marine Bio-Acoustics
held at the American Museum of Natural History, New York, April 13–15, 1966
PERGAMON PRESS – OXFORD & NEW YORK – 1967

IDENTIFICATION OF BIOLOGICAL SONAR TARGETS FROM BODY-MOTION DOPPLER SHIFTS*

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THE American high-seas tuna fishery is principally a purse seine fishery. The use of conventional pulsed sonar to locate schools of tuna and to direct the setting of the purse seine has been tried by two vessels. The operation has not been successful, however, for two reasons. First, the schools often move so rapidly and erratically that pulsed sonar with a scan rate of only a few degrees per second can not follow them. Second, some of the several species of fish encountered on the fishing grounds are so small that they become gilled in the meshes of the net; the result is lost fishing time, and often shark damage to the gear. These problems can be overcome by using a sonar system that incorporates both a high scan rate and a method of size discrimination.

Our approach at the Tuna Resources Laboratory has been to use a Continuous Transmission Frequency Modulated (CTFM) sonar, coupled with a high-resolution frequency analyzer. The frequency analyzer resolves the frequency shifts (Doppler) caused by motion of the fish and by fish-body flexure and separates the echoes into three classes: targets that are stationary (no target Doppler); targets that show gross motion (narrow-band Doppler); and targets that show complex motion (broad-band Doppler). Broad-band Doppler was found to be characteristic of fish schools, and it may be possible to analyze frequency shifts caused by body flexure of fish to estimate the size of the individuals in the target school.

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* The vessel used was on loan from the U.S. Navy; the system was designed, manufactured, and installed by Straza Electronics, a division of Straza Industries, under Contract No. 14–17–007–252 with the Department of the Interior, U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries. Although the working arrangement was basically financial, the engineering and scientific effort and the wholehearted cooperation of the personnel of Straza Electronics was exemplary. A portion of our investigation was conducted in the territorial waters of Mexico at Los Coronados. Entry was made possible through the courtesy of the Dirección General de Pesca e Industrias Conexas, Departmento de Estudios Biológicos Pesquiros, whose cooperation is greatly appreciated.

TABLE 1. SPECIFICATIONS OF SM506 SONAR SYSTEM

Projector source frequency	60–75 kHz, 70 kHz in CTD mode
Projector source level	+95 db re μbar/volt at 1 yd
Projector horizontal beam width	20°
Projector vertical beam width	20°
Receiving hydrophone horizontal beam width	4°
Receiving hydrophone vertical beam width	10°, 20°
Open circuit receiving hydrophone sensitivity	−75 db re 1 volt/μbar
CTFM ranges	100, 200, 400, and 800 yd
Horizontal scan rate	25°/sec on 100, 200, and 400 yd 10°/sec on 800 yd
Presentation	
CTFM – 7-in. plan position indicator scope 5-in. "A" type display on CRT Audio	
CTD – 7-in. relative bearing display 5-in. frequency spectrum display Audio	
Data Storage	
Video, audio, range, servo, and mode information to multiplexer and Ampex Model SP–300 tape recorder. Playback through system.	

EQUIPMENT

Our target-classification sonar system was a modification of a Straza Electronics 500 series CTFM sonar (Table 1). CTFM sonar has several desirable features for use on pelagic fishes. A wide-beam projector continuously fills a large volume of water with sound, the frequency of which is repeatedly varied from low to high in a saw-toothed manner. A narrow-beam hydrophone rapidly scans the ensonified volume (25°/sec in our sonar). All targets in the projector beam return echoes at a frequency that differs with time (or range) from the projected frequency. Mixing of the transmitted and received frequencies produces a difference frequency corresponding to a range. This is a continuous process that gives a much faster information rate than is possible with a conventional pulsed sonar system. This high information rate makes it possible to maintain contact with fast-moving schools. Each target is a source of continuously reflected sound. The hydrophone scans each target for a time equivalent to several pulse lengths of a pulsed sonar; as a result the target returns are averaged. Such signal averaging of short-term fluctuations in echo strength increases the likelihood of detection of any particular target.

Because range information was obtained from a difference frequency, CTFM sonar already had some of the circuit design that was required for Doppler resolution. The addition of a second mode of operation, Continuous Transmission Doppler (CTD), that used most of the CTFM circuits plus a frequency analyzer of higher resolution, permitted our sonar to be used to both locate and classify a target. The system components were packaged to mount on vessels of convenience; the underwater unit was mounted on an over-the-side column.

PROCEDURE

When a fish school was located, the CTFM mode was used to position the boat 100 to 200 yd from the school. If the school was moving we tried to match its velocity and direction of movement with the vessel. When the school was positioned, the sonar scan was locked and the system placed in the CTD mode. In this mode a continuous 70 kHz tone was transmitted from the sonar projector. The echo of this tone plus Doppler information was received by the hydrophone, mixed and filtered to remove the portion corresponding to 70 kHz, and fed to the spectrum analyzer. The spectrum analyzer had a Delay Line Time Compressor (DELTIC) to raise the Doppler frequency information by factors of 2 or 4×10^3 and allow frequency resolutions of 3.33 Hz or 1.67 Hz over a band of ± 600 Hz or ± 300 Hz. The Doppler spectrum could be displayed on a cathode ray tube (CRT) and photographed, recorded on magnetic tape, or the same information could be stored and displayed repeatedly on the CRT by locking th DELTIC.

The incoming signal was sampled by logic circuitry to convert Doppler frequency information into digital form. This digital information was loaded into the delay line at the rate of 100 μsec/bit when the ± 600 Hz Doppler band was used and at 200 μsec/bit when the ± 300 Hz band was used. Since the DELTIC could store 3000 bits of information, the initial loading time of the analyzer was 0.3 sec or 0.6 sec, depending on the resolution selected. After the line was loaded, new Doppler information could be added and old information dropped at the rate of about one bit/150 μsec. The output of the analyzer then was analogous to a photographic time exposure of the Doppler received in a 0.3- or 0.6-sec interval. The analyzed Doppler was presented as video on the CRT at 5 sweeps per second. Frequency was displayed along the horizontal time line with center frequency (no Doppler) at the center of the scope, up Doppler to the left, and down Doppler to the right (Fig. 1). Vertical deflection depends on the number of times a particular frequency was present during the load time of the delay line. A single frequency was shown as a single high spike, whereas multiple frequencies were displayed as many spikes of lower amplitude.

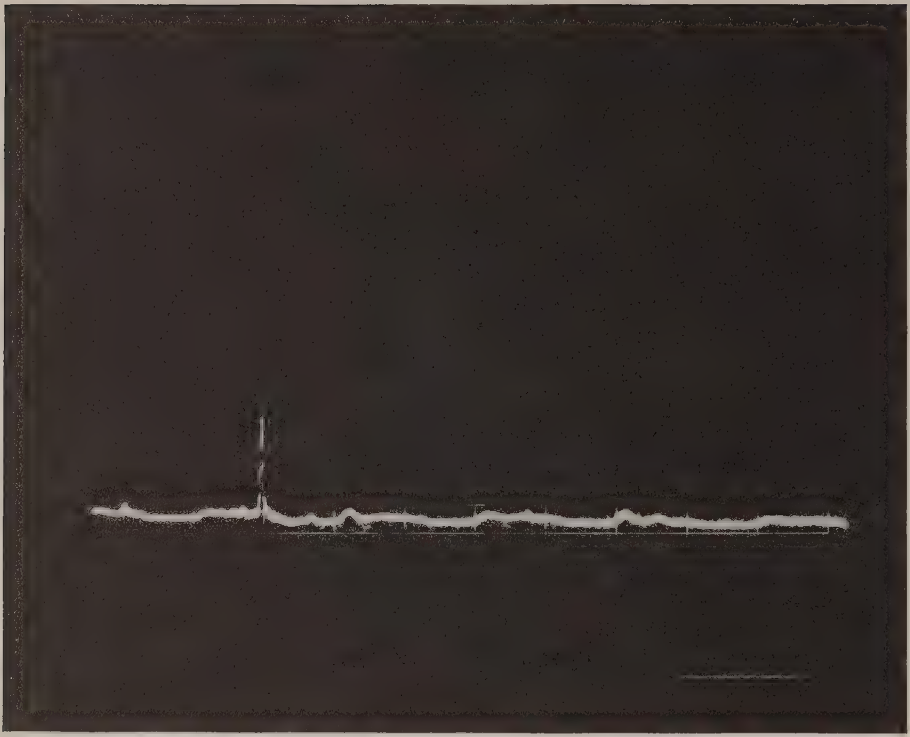

FIG. 1. Narrow-band Doppler from floating kelp patch. Range 200 yd, resolution 30 Hz/div, vessel closing at 2 to 3 kts.

THEORETICAL DOPPLER SOURCES.

In the system described, the potential sources of Doppler were:

1. Ocean currents.
2. Sea state.
3. Pitch and roll.
4. Vessel velocity.
5. Directional velocity of target.
6. Undulatory velocities of target.

The basic Doppler equation is:

$$\Delta f' = f_s \frac{V_L - V_s}{u + V_s - V_m}. \tag{1}$$

where $\Delta f'$ = change in transmitted frequency,
f_s = frequency of the source,
u is the velocity of sound in the propagating medium,
V_L is the velocity of the listener along the line of centers,
V_s is the velocity of the source along the line of centers,
and V_m is the velocity of the medium along the line of centers.

Since ocean currents V_m and also the velocity of the vessel V_s are small with respect to the velocity of sound u, equation (1) can be rewritten as

$$\Delta f' = f_s \frac{V_L - V_s}{u} \tag{2}$$

Equations (1) and (2) apply to an active source and passive listener. Because the reverse was true, namely the source was acting as a reflector and the listener was transmitting, the difference frequency was doubled and the detected difference frequency was:

$$\Delta f = 2\Delta f' = 2f_s \left(\frac{V_L - V_s}{u}\right) \tag{3}$$

Taking $u = 1.5 \times 10^5$ cm sec $^{-1}$, $f_s = 70$ kHz and $\Delta f = 300$ or 600 Hz (the two band widths of the CTD system), the maximum detectable velocity along the line of centers was:

$$V_L - V_s = V_{\max} = \frac{\Delta f}{2f_s} u = K_1 \Delta f \tag{4}$$

where K_1 at 70 kHz = 1.07

or $V_{\max\ 300} = 321$ cm sec $^{-1}$ = (6.2 kts)

$V_{\max\ 600} = 643$ cm sec $^{-1}$ = (12.4 kts)

and the velocity resolution was:

1.8 cm sec $^{-1}$ (0.035 kts) 300 Hz band width

3.6 cm sec $^{-1}$ (0.07 kts) 600 Hz band width

Sea state. Maximum water-particle velocity for sea state 3 (to date we have confined work at sea to periods of calm weather) can be taken as 250 cm sec $^{-1}$ for a wave 1 m high with a 5 sec period. From (3) this movement gives a maximum Doppler of about ± 230 Hz. This frequency varies sinusoidally between the two extremes. From the system's point of view, a continuous noise spectrum including all the frequencies (velocities) in this band should be present. Because the receiver noise level in our system was about the same as the signal strength from this sea state, interference from this source did not prove bothersome.

Pitch and roll. With the projector and hydrophone trained abeam of the

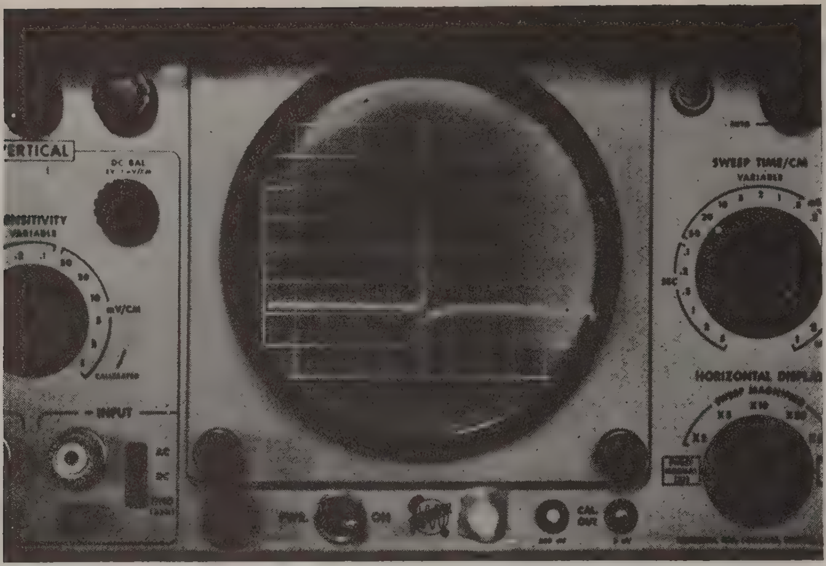

FIG. 2. Typical narrow-band Doppler from a small metal triplane at 10 yd: no motion, large spike at 0 Doppler; horizontal scale 60 Hz/div. Vertical scale relative (see text).

vessel, the hydrophone was subject to a cyclic roll velocity that varied in an unpredictable long-term manner. Typically, the velocity of the array on the end of a 3-m arm for a 5° roll with a period of 2 sec would give a $\Delta f_{\max}$ of ± 76 Hz. Pitch-and-roll Doppler is indistinguishable from Doppler produced by single undulatory targets with similar periods, and must be minimized by selecting optimum sea conditions and vessel headings. In this study, these conditions were met, and Doppler caused by pitch and roll was minimized.

Vessel velocity and target velocity. Doppler resulting from these causes appeared as a displacement of the center-frequency (70 kHz) reverberation or target blip to the left or the right, depending on the direction of the relative velocity component along the line of centers (Fig. 1). The contribution of vessel velocity could be calculated from equation (3), or made zero by either stopping or training the array to 90° or 270° relative to the direction of travel. What remained was the target-velocity component along the line of centers. This velocity component was typified by a narrow-band Doppler presentation displaced from the center by a frequency (Δf) corresponding to V_s (Figs. 2 and 3).

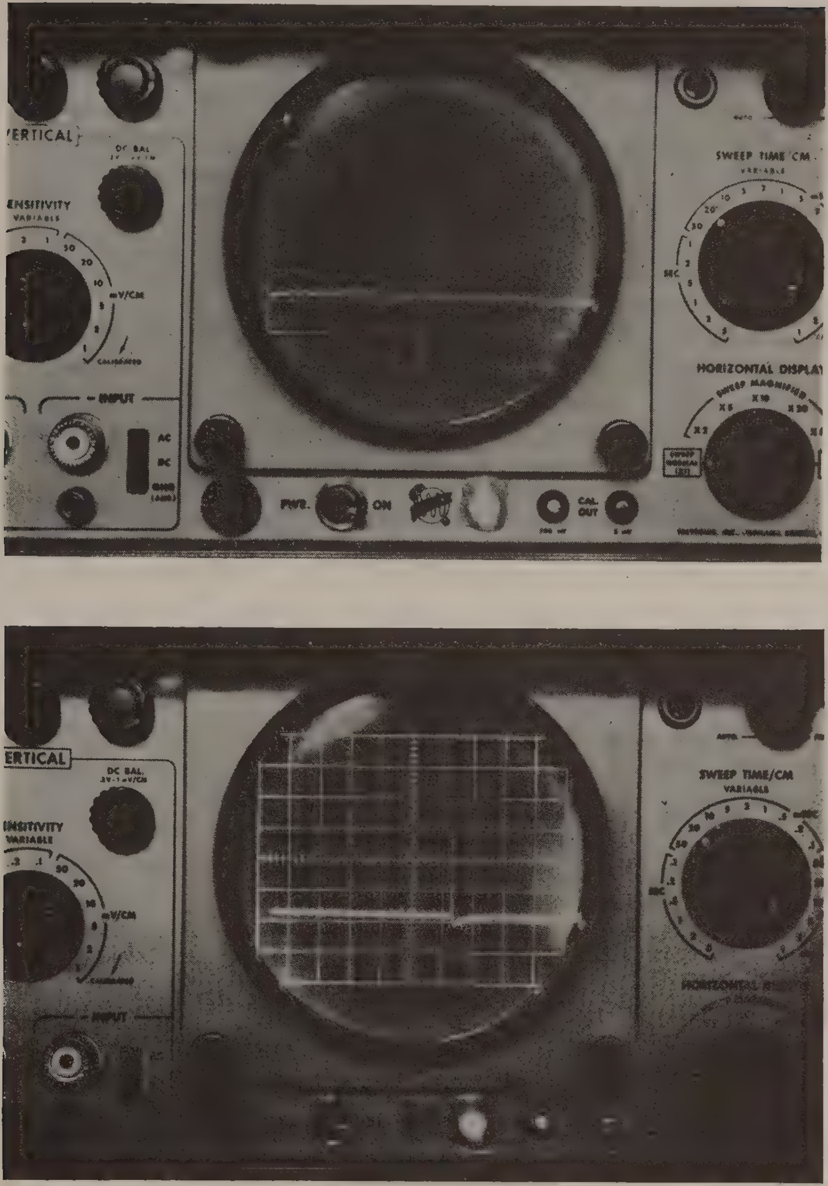
ERTICAL
DC BAL.
ENSITIVITY
VARIABLE
mV/CM
INPUT
AC
DC
PWR.
ON
CAL.
OUT
SWEEP TIME/CM
VARIABLE
SEC
HORIZONTAL DISPLAY
SWEEP MAGNIFIED
X2
X5
X10
X20

FIG. 3. (a) Motion of triplane toward hydrophone, spike displaced to left; (b) motion away from hydrophone, spike displaced to right. Horizontal scale 60 Hz/div. Vertical scale relative (see text).

Undulatory velocities of the target. The most complex Doppler was due to undulatory motions of the target or, in a school of fish, directional movement of the school and undulatory motion of the individuals in the school. Locomotion of most fish depends on movement of the body and tail. Maximum undulatory Doppler is produced when the side of the fish is normal to the sound beam. In this aspect, both the target strength of the moving portion and its velocity component along the line of centers are maximum. Under these circumstances the major contribution to the Doppler comes from tail movement and body flexure. Bainbridge (1958) has shown that a definite relation exists between swimming speed (in body lengths sec $^{-1}$) and the frequency and amplitude of the tail beat. He found swimming speed directly dependent on the amplitude of the tail beat, up to 5 tail beats per second. At frequencies higher than 5 beats per second, a constant side-to-side amplitude of about 0.20 body length was reached. Above 5 beats per second, swimming speed depended solely on the frequency of tail-beat and the size of the fish; here the following empirical relation was found.

$$V_f = \frac{L_f(3f_f - 4)}{4} \tag{5}$$

where V_f = speed of fish in cm sec $^{-1}$
L_f = total length in cm
f_f = tail beats per second

We believe we may be able to estimate fish size from equation (5). Swimming speed V_f can be obtained by matching vessel velocity with the school velocity. Tail-beat frequency theoretically can be calculated from Doppler information. Because the load time of the system (0.3 or 0.6 sec) is long with respect to most tail-beat frequencies, we should see on our display a spectrum of frequencies, broad-band Doppler, in which the maximum Δf corresponds to tail velocity as the tail crosses the center line. If the assumption is made that tail-beat motion is harmonic, it follows:

$$V_{T\,\max} = A_f 2\pi f_f \tag{6}$$

where V_T = velocity of tail tip,

and A_f = amplitude or 0.1 L_f (after Bainbridge, 1958)

since (4) $V_{\max} = K_1 \Delta f,$

then $K_1 \Delta f = A_f 2\pi f_f$ or $0.1\ L_f(2\pi f_f)$

and

$$f_f = \frac{K_1 \Delta f}{0.2\pi L_f} \tag{7}$$

from (5) $$V_f = \frac{L_f(3f_f-4)}{4} \quad \text{when} \quad f_f > 5$$

then $$V_f = \frac{L_f\left(\dfrac{3K_1\Delta f}{0.2\pi L_f}\right)-4}{4} \quad \text{or} \quad \frac{\dfrac{3K_1\Delta f}{0.2\pi}-4L_f}{4} \tag{8}$$

take $$K_2 = \frac{3K_1}{0.2\pi} \approx 5$$

and (8) becomes $$V_f \approx 1.25\,\Delta f - L_f \tag{9}$$

or $$L_f \approx 1.25\,\Delta f - V_f \tag{10}$$

and $$f_f \approx 1.67\,\Delta f L_f \tag{11}$$

If a school of fish traveling $V_f = 160$ cm sec^{-1} (3 kts) gives $\Delta f_{\max} = \pm 150$ Hz, then from equation (10), fish length $L_f = 25$ cm and from equation (11), frequency of tail beat $f_f = 10$ beats sec^{-1}. For any swimming speed Δf increases 0.8 Hz for each centimeter of body length (Fig. 4). The 1.67 Hz resolution in the ± 300 Hz band width is theoretically capable of determining fish size to within 2 cm.

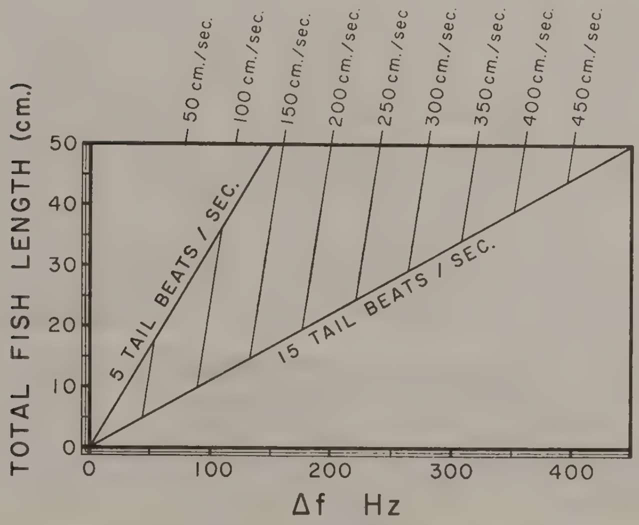

FIG. 4. The relation between fish length and tail-beat Doppler at various swimming speeds. The relation is non-linear at tail-beat frequencies less than 5/sec; frequencies greater than 15/sec probably are rare.

Body motion as well as tail motion should contribute to undulatory Doppler. On the basis of area alone the body should present a target which is detectable at greater ranges than the tail. Fishes such as trout that swim with a sinuous motion (studied by Bainbridge, 1958; see also Gray, 1957) may be expected to have a body-flexure Δf spectrum lower in frequency and out of phase with the tail-beat Δf spectrum. Because of the higher target strength of the body, this body-flexure Δf should be detected at greater ranges and may provide a diagnostic character for certain types of fishes. A Doppler pattern taken when a school of fish that have a sinuous swimming motion is 400 yd away may show a Δf band from body motion, alone. At some closer range the Δf band may show an increase in frequency caused by the addition of tail-beat signals. The scombroids, on the other hand, swim with the body rigid and perhaps will show only tail-beat Δf. Scombroids may show only a constant Δf band of frequencies that is independent of range.

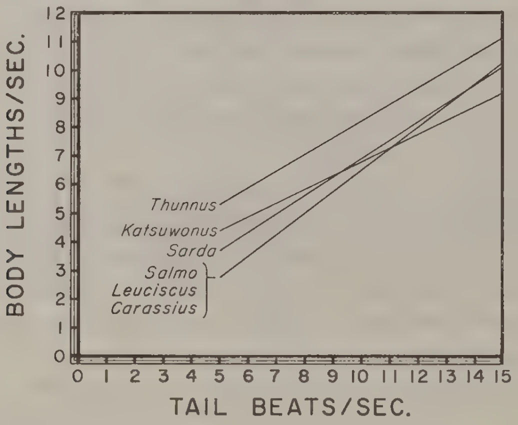

FIG. 5. The relation between swimming speed (body lengths/sec) and tail beats/sec for three scombroids and three species studied by Bainbridge (1958).

Although tail-beat amplitude has not been determined for scombroids, the relation between tail-beat frequency and swimming is available (Fig. 5). The slopes of the speed-frequency lines for scombroids (Magnuson and Prescott, in MS.; Yuen, in press) differ from those given by Bainbridge (1958). This difference may be related to the difference in swimming motion.

The non-linearity of Bainbridge's equation below 5 tail beats per second, the differences in slope of the speed–frequency curve for scombroids, and our assumption that tail-tip motion is harmonic will complicate the reconciliation of actual measurements with theory.

Finally, many schooling fish form mills or balls in which individual orientation is not uniform. Doppler from such a ball should show individual velocities along the line of centers as well as undulatory Doppler, and the two will be very difficult or impossible to separate. Balling occurs primarily with small fishes, however, and is readily distinguishable as such in CTFM mode.

EXAMPLES OF DOPPLER PATTERNS

The system described has been operational for only a few months – unfortunately during a time of scarcity of large fish. We have made some measurements on schools of small fish that look promising and a few

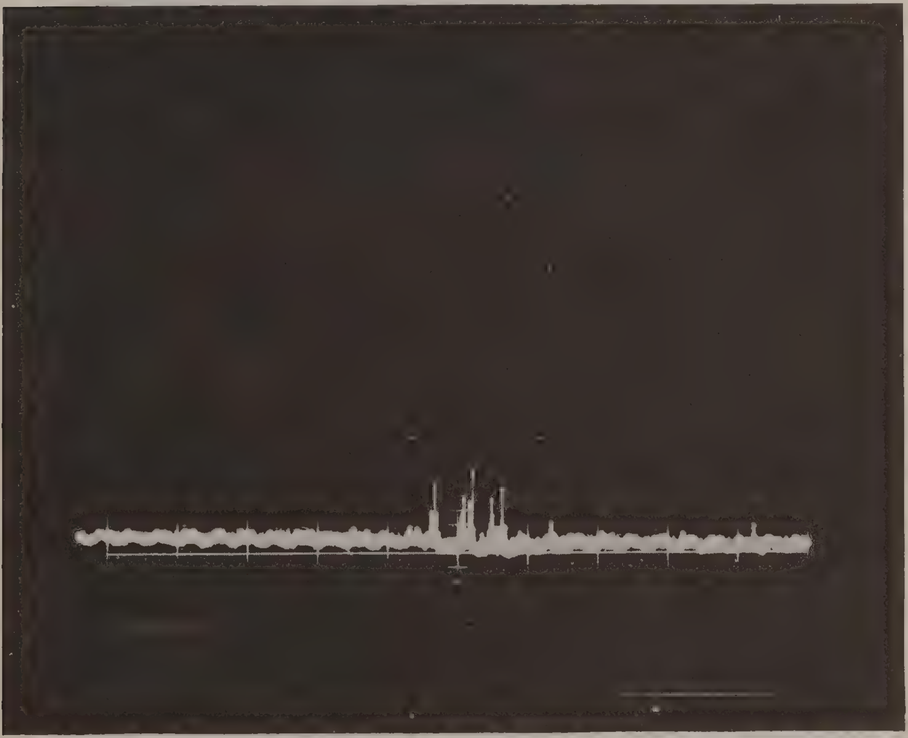

FIG. 6. Broad-band Doppler from school of bait fish. Range 50 yd, resolution 60 Hz/div. Vessel stopped.

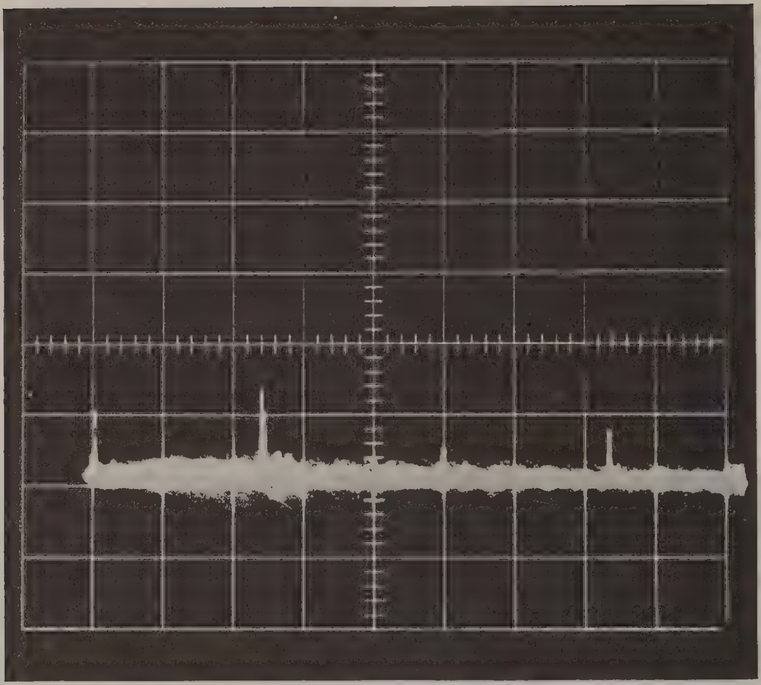

FIG. 7. Reverberation Doppler, same area as Fig. 5, but no target. Resolution 60 Hz/div, vessel underway 4 to 5 kts.

interesting measurements on single large animals. Figure 6 shows what is evidently typical of Doppler produced by small fish. The fish were probably anchovies or atherinids about 10 to 15 cm long but were not identifiable or visible from the surface. The slight Doppler ± 30 Hz was most likely caused both by motion of individual fish in the school and by undulatory motion. This Doppler pattern differed demonstrably from reverberation Doppler, which is the result of scattering of the sound beam by numerous small objects in the water (Fig. 7). The Doppler in Fig. 8 was caused by a single target fish approaching the boat. This was a fish about 50 cm long from a school, probably of bonito *(Sarda chiliensis)*. The school was separable into individuals in CTFM mode at close range, whereas the previous targets could not be resolved, even at 40 yd.

Figure 9 was probably a bio-acoustic phenomenon; it was taken in the vicinity of a scattered school of porpoise (*Tursiops* sp.). The porpoise were

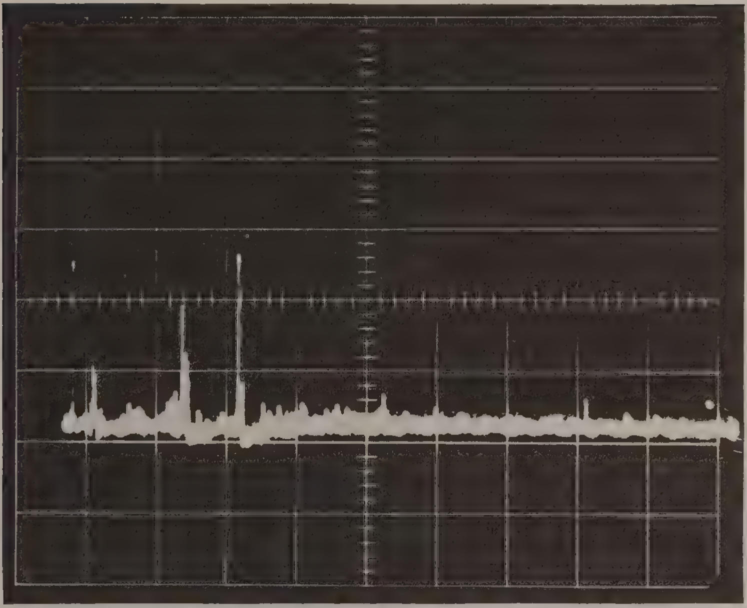

FIG. 8. Single fish (probably *Sarda chiliensis*) approaching vessel. Resolution 60 Hz/div, vessel stopped.

feeding and seemed to avoid the vessel. It is unlikely that an animal was in the beam when this Doppler was taken. The low-amplitude frequency spikes were probably caused by sounds made by porpoise.

SUMMARY

1. Biological sonar targets cause Doppler shifts in the transmitted-received sonar frequency. Part of the Doppler is produced by target velocity and part by flexures of the target itself—in fish by swimming motions. Because it is likely that body-motion Doppler will vary in frequency for different sizes and species of fish, it may be possible to use Doppler information for target classification.
2. A Continuous Transmission Frequency Modulated Sonar was modified to transmit a steady 70 kHz tone. The received target echo was processed by a digital-frequency multiplication technique using a Delay Line Time Compressor which permits Doppler resolution of 3.33 Hz over a ± 600 Hz band width, or 1.67 Hz over a ± 300 Hz band width, analysis time being 0.3 sec and 0.6 sec, respectively.

3. Aside from target produced Doppler, several potential Doppler sources were present: currents, wave motion, vessel pitch and roll, and vessel velocity. All of these sources were eliminated or minimized by selecting optimum operating conditions or by proper vessel maneuvering.
4. Under favorable conditions, target Doppler could be classified into narrow-band Doppler characteristic of inanimate objects which had only a constant velocity component, and broad-band Doppler characteristic of biological targets which had complex and varying components. Interspecific variations in the broad-band Doppler patterns were found between small fish schools and single large scombroids.
5. Attempts to obtain Doppler from porpoises was complicated by the biological sounds they produced. These sounds include those frequencies ± 600 Hz of 70 kHz and effectively mask the actual target signal.

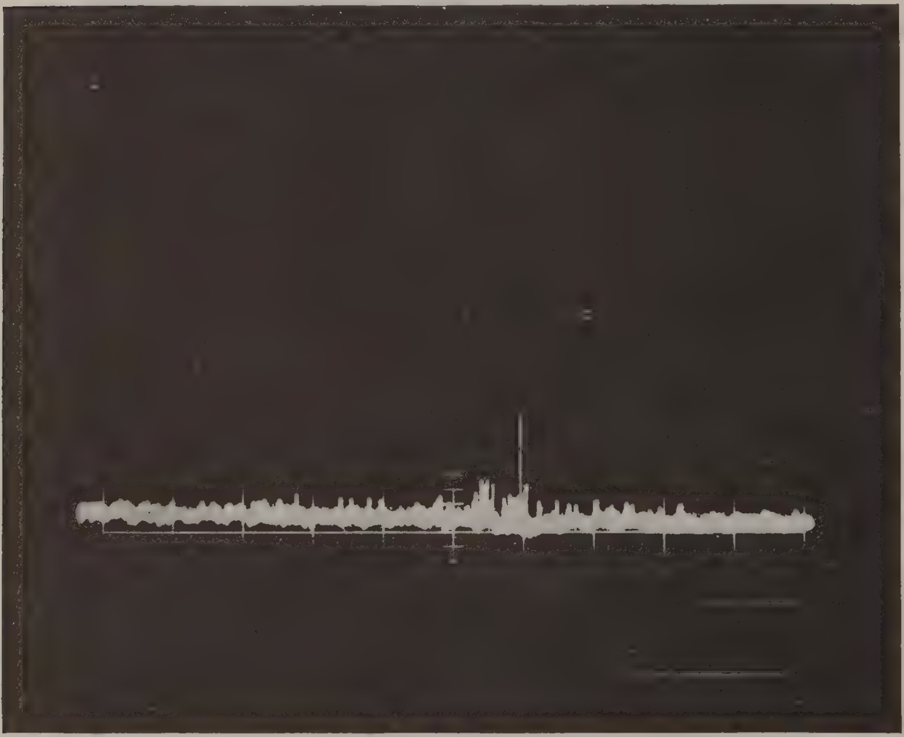

FIG. 9. Porpoise sonar displayed as Doppler. Resolution 60 Hz/div, vessel stopped (see text).

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DISCUSSION

DR. SCHMITT: First, I wonder whether the analysis that's been done includes the amplitude modulation that has to do with the swimming motion of the fish. Was this interpreted as an FM which, in turn constitutes a damper source? Was this considered as a portion of the source?

I think this is interesting because many of us would like to design shaped filters that would conform to such reflections representing a characteristic modulation pattern introduced by the fish.

The second question is about the matter of the motion of the system vs. the water, and water vs. the fish. If you can wash out the first part of this, this would be very desirable. I believe there are some analyses that permit you to look at the average coherent response from the diffuse scattering of the media – presuming water in general to be stationary, thereby allowing you to do your signal processing to a greater depth looking at the little Doppler returns superimposed on it.

MR. HESTER: I have to respond to your question with a question. I didn't understand that first question. Would you please rephrase it?

DR. SCHMITT: How did you analyse the Doppler motions associated with the accelatory movement of the fish – presumably thinking of the fish as a number of pieces of protoplasm moving to and from the transmitter.

In addition to this, as the fish moves it presents a substantially greater and lesser target area, and consequently a stronger and weaker echo, and this amplitude modulation constitutes an incidental frequency modulation which becomes equivalent to a Doppler.

MR. HESTER: That's one of the drawbacks of our system. We lose signal strength information in our analysis. One of the things we would like to do is to pick up a target at an extreme range, say 300 yd, and slowly close and watch how the Doppler changes as we approach. In this case, we might pick up the differences that do resolve in the changing target strength of various portions of the fish.

Does that answer your first question?

DR. SCHMITT: Yes.

MR. HESTER: Regarding your second question, there are a number of things you can do with this type of system to get rid of these inherent problems, and in our study which is preliminary, we hesitate to invest the funds. In the area we work, Southern California, our weather conditions are such that we can pick conditions so that most of these problems with sea return, roll, and pitch, are negligible.

DR. MARSHALL: I suppose this is a case of size recognition. For example, if one takes the Bainbridge equation, you get something like 30 ft/sec for the velocity of the fish. When they swim are they in fact cruising at 2–3 knots? Are the amplitudes of the tail beats wider than when they're going faster?

MR. HESTER: Bainbridge found that it increased until above 5 tail beats a second, amplitude was constant. This has not been done as far as I know for any of the scombroids, and I'm reasonably sure that they will find that amplitude will change in some similar manner as tail beat increases.

Dr. Busnel: In your paper you say you assume a harmonic beat of tail with not too much bend in the axis as it moves from side to side. I suppose there's nothing coming from the gills of these fish. When they swim they swim with the mouth half open. I think this considerably simplifies your problem.

I think it amusing to wonder how fish in a school know each other? How do they sort themselves out according to size? Is it that the large ones can slip past the little ones, and they just leave them behind? Or is it that they can scrutinize each other in the lateral line system? In other words, can they do something analogous to what you're doing in the schooling?

Mr. Hester: The most immediate question I'd like to see answered is this question of amplitude and frequency.

You mentioned opercular movement and this ties in to body flexure. The approach we're using is strictly empirical. We tried an experimental approach in a pool, and we ran into so many problems with multiple paths that we abandoned this in favor of work in the field where visual contact is seldom possible.

I think when we have a chance to look at some more of these schools, we may begin to see some type of pattern emerge. I think it will probably be a range signal strength type relationship. The signal strength of the tip of a fish's tail is relatively not very great compared to, say the middle of his body, and it's quite likely that we'll find that these frequencies will increase as range decreases.

Mr. Wood: I wonder with the Doppler if you're contributing to what you're getting. You said it probably was not great. Have you done any experiments to see what order of echo you can get from the fin of a scombroid fish?

Mr. Hester: When we first went into the CTFM sonar question, there were some target strength measurements made of both fresh and frozen scombroids, and we found at the frequencies we're using that almost any portion of the fish gives you a fairly strong signal.

We went so far as to suspend a skipjack in the beam of a transducer, and strip off various portions until we had only the skeleton and the tail. The over-all target strength dropped from about −25 to −30 dB.

Mr. Wood: The fish was dead?

Mr. Hester: Yes.

Mr. Wood: What about post mortem effects?

Mr. Hester: We did find with living and dead fish (not scombroid) that at the higher frequencies the post mortem effects were considerably less than they were down around 10–30 kHz.

Dr. Mackay: It was really pleasing to hear of your success because there have been so many failures in this Doppler shift business. Could you tell us—do you have any secret of success?

Do you specifically avoid regions where there are internal waves in the ocean or do you take the beam off the surface? Do you never go out when the sea is rough? Does it work as well in the swimming pool as in the ocean?

Mr. Hester: We found it didn't work very well in a swimming pool. It's been successful in the ocean. Yes, we pick our weather conditions very carefully. We work at very short ranges. Our beam is 10 degrees wide vertically, and it touches the surface and sometimes it touches the thermocline. We try to work with strong targets. This is a matter of finding a large school of fish. Our spectrum analyzer is a DELTIC unit which effectively averages over either 3 or 6 tenths of a second period, all the frequencies that are present. This gives us effectively a very narrow band pass which gives us a much higher signal-to-noise ratio.

THE DISTRIBUTION OF JUVENILES OF FOUR SPECIES OF TUNAS IN THE PACIFIC OCEAN

by

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ABSTRACT

Juvenile (12-300 mm) skipjack tuna (*Katsuwonus pelamis*) have been collected throughout the western and central Pacific Ocean in tropical and subtropical waters, and a few have been taken in the eastern tropical Pacific. Juvenile yellowfin tuna (*Thunnus albacares*) are more common than skipjack tuna in the eastern tropical Pacific, but are reported from fewer locations in the central and western Pacific. Juvenile albacore (*T. alalunga*) have been found only at high latitudes in the western and central Pacific. The few recorded captures of juvenile bigeye tuna (*T. obesus*) are from the western tropical Pacific. Present methods of collecting juvenile tunas have several deficiencies that greatly hinder their effectiveness. Midwater trawls offer certain advantages over other methods, but further experimentation with small-mesh nets of large size is needed.

INTRODUCTION

Quantitative information on the spatial and temporal distribution and abundance of tunas in their early life stages is essential to the analysis of population dynamics on the basis of size and mortality of the recruitment stocks. Dependent on such information are solutions to problems such as success or failure of year classes, differential distribution and availability of age groups, and reproductive isolation on subpopulations. Two requirements are basic to the acquisition of additional knowledge about immature tunas. First, we must obtain the young at many stages of development, preferably in a complete series from egg to adult. Second, we must be able to identify the developing tunas.

Proc. Indo-Pacific Fish. Coun., 12(II): 79-99.

Tuna eggs are often collected in plankton nets, but it is not yet possible to identify most scombrid eggs to species (Ueyanagi and Ahlstrom, 1963). On the other hand, identification of larval tunas, which are also frequently taken in plankton nets, has received considerable attention in recent years (e.g., Matsumoto, 1958, 1962, 1963; Ueyanagi and Watanabe, 1964; Yabe and Ueyanagi, 1962). Juvenile tunas, particularly skipjack tuna, may also be identified with fair certainty, by using larval and adult characters. Schaefer and Marr (1948), Eckles (1949), Wade (1950), Mead (1951), Matsumoto (1961), Yoshida (1965), and others have described juveniles of several species of tunas. Despite progress in identification, however, collection continues to be a serious problem. Juvenile tunas are exceedingly difficult to capture between the time at which fins are completely formed (at a length of about 15 mm) and the time at which a few adolescent fish begin to appear in commercial catches in some areas (at lengths of about 35 cm).

OBJECTIVES

In this review I summarize what has been published, to the best of my knowledge, on the capture of juvenile skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*), albacore (*T. alalunga*) and bigeye tuna (*T. obesus*). For the purpose of this paper, I designate juvenile tunas as those not longer than 300 mm, and include them in the distributional records unless they were taken by commercial fishing. I exclude most tunas shorter than about 12 mm from distributional records, but include a few records of shorter tunas because they were caught by a method other than towing a plankton net (which I consider a sampling device for tuna larvae, rather than juveniles).

Before the geographical distribution of the four species is considered, some of the merits and deficiencies are discussed for three methods that have been used to collect juvenile tunas.

COLLECTING METHODS AND LIMITATIONS

Existing information on distribution of juvenile tunas has resulted primarily from the extensive but sporadic use of three collecting methods: (1) "dip netting" at "night-light" stations (scooping up the fish with a long-handled net as they swim to an artificial light suspended at the surface as the vessel drifts at night); (2) searching the stomach contents of pelagic predators; and (3) towing various sizes of small-mesh midwater trawls at the surface and in deeper water.

Dip netting at night-light stations has been rather successful for juvenile yellowfin tuna in the eastern Pacific. But in the same area, the method has taken very few juvenile skipjack tuna and no juvenile albacore or bigeye tuna. In the central and western Pacific areas, dip net collections account for less than one-fifth of the juvenile skipjack tuna and none of the juvenile albacore or bigeye tuna upon which this review is based. Perhaps the major difficulty associated with this collecting method is that the adverse weather commonly encountered on the open sea prevents night-light stations, except in lagoons or on the leeward side of islands. Dip netting will undoubtedly continue to supply us with juvenile tunas from certain protected locations, but the requirement for calm water severely restricts its use.

Were it not for their presence in stomach contents, our knowledge of the occurrence of juvenile tunas in the Pacific would be far more meager than it is. Most records of albacore and bigeye tuna reported here have resulted from examining stomach contents. Juvenile skipjack tuna tend to be even more common than other juvenile tunas in stomach of adult tunas and billfishes (Nakamura, 1965; Koga, 1958). But stomach sampling has a few obvious deficiencies. Specimens are sometimes in such poor condition that further biological studies are difficult or impossible, even though hard parts alone are commonly sufficient for identification. Moreover, in contrast to dip netting or trawling, the exact depth of capture frequently is unknown. Finally, it is conceivable that juveniles of one species of scombrid might be eaten more often than another for reasons other than its greater abundance in an area. Watanabe (1958) observed, for example, that juvenile "Katsuwonidae" (probably skipjack tuna) were eaten by yellowfin tuna but not by bigeye tuna in the western equatorial Pacific. Such a situation might arise because of greater similarily of predator and prey distributions in one instance than in another.

Dip netting and stomach sampling have provided practically all the juvenile tunas upon which our present knowledge is based, but the several deficiencies associated with these techniques have long suggested the need for a better method--one which will allow us to sample whenever and wherever we choose, and will give some measure of effort for quantitative comparisons of abundance of each species within and among the various areas at selected depths and times. In recent years, the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, has paid particular attention to midwater trawls. King and Iversen (1962) and Matsumoto (1961) have discussed the effectiveness of various sizes of trawls for collecting juvenile tunas in the central Pacific. In general, the larger "Nanaimo" trawl used by Matsumoto in 1958 was more effective in collecting juvenile tunas than the smaller nets used by King and Iversen in 1951-56. More recent trials with other large nets indicate that further experimentation with large, small-mesh nets should be productive.

As a sampling method for juvenile tunas, trawling seems particularly desirable, even though several men are required to set and retrieve the net for each tow. Trawls are capable of capturing juvenile tunas without having to rely on their attraction to light or their consumption by predators. Tows can be made at any chosen depth, time, or place without undue regard for the weather. Finally, juvenile tunas collected with trawls are usually in excellent condition. Identification is thus facilitated, and it is possible to carry out biological studies that require whole, unmutilated specimens.

GEOGRAPHICAL DISTRIBUTION

Pacific Ocean records of collection of juvenile skipjack tuna, yellowfin tuna, albacore and bigeye tuna are discussed according to area of capture. For this purpose, I arbitrarily divided the Pacific into three areas: western (long. 120° E to 180°), central (long. 180° to 120° W), and eastern (long. 120° W to west coast of Americas).

Positions of capture of juvenile tunas are plotted on distribution maps. If an author did not specify an exact location of capture, the record was not included on a distribution map unless the place of collection was reported to be close to an island or other land feature for which the geographical position is known.

Juvenile skipjack tuna

In the western North Pacific, many juvenile skipjack tuna have been taken from stomachs of pelagic fishes caught from the Equator to lat. 32° N, except in the area surrounding Wake Island (lat. 19°17' N, long. 166°35' E) (Table I and Fig. 1). In the southwestern Pacific, Sun (1960) recorded the capture of one small skipjack tuna (actually a larva) just south of the Equator. Yabe, Yabuta, and Ueyanagi (1963) indicated (their Fig. 11) that juvenile skipjack tuna have been collected northeast of Australia and in the vicinity of the Philippine Islands and New Guinea. Unfortunately, exact positions of capture and other catch data have not been published and are not available (S. Ueyanagi, personal communication).

In the central Pacific, juvenile skipjack tuna have been collected from lat. 22° N near Hawaii to lat. 23° S near the Tonga Islands, but there are large gaps in the distributional record. Apparently no juvenile skipjack tuna have been taken near Johnston Island in the North Pacific (lat. 17° N, long. 168°30' W). None have been recorded in the Southern Hemisphere between lat. 9° S and 23° S, although several food studies have indicated that juvenile skipjack tuna occur there. Koga (1958) found juveniles in the stomachs of tunas and billfishes caught near the Fiji Islands, and Nakamura (1965) remarked that juvenile skipjack tuna are a very important food of adults of that species around the Tuamotu Archipelago. Juvenile skipjack tuna have also been found in the stomachs of billfishes near Samoa (H.O. Yoshida, personal communication).

In the eastern tropical Pacific, only 10 skipjack tuna were taken by dip netting during 1948-61 (Klawe, 1963). At the same night-light stations, 136 yellowfin tuna, 229 black skipjack (*Euthynnus lineatus*), and 3,464 frigate mackerel (*Auxis thazard*) were taken. Alverson (1963) found only one skipjack tuna in the stomachs of 3,856 yellowfin and skipjack tuna caught in the eastern Pacific. In the same stomachs he found 3 yellowfin tuna, 5 black skipjack and 103 frigate mackerel. From the relatively infrequent occurrence of skipjack tuna it would seem, as Klawe (1963) and others have suggested, that the eastern tropical Pacific is not an important spawning area for the species.

Table I. Pacific Ocean records of collection of juvenile skipjack tuna (Katsuwonus pelamis).

Location of collection[1]						
Latitude	Longitude	Date	Number collected	Total or fork length (mm)[2]	Method of collection[3]	Reference or collector
Western Pacific						
32°04' N	177°45' E	Jan. 1949-50	3	230-300	S (BE)	Suda (1953)
32°00' N	177°57' E	Jan. 1949-50	1	285	S (BE)	Suda (1953)
31°55' N	177°53' E	Jan. 1949-50	1	300	S (BE)	Suda (1953)
31°55' N	177°45' E	Jan. 1949-50	2	ca 300	S (BE)	Suda (1953)
31°16' N	130°19' E	June 1924	3	100-140	D	Kishinouye (1926)
29°51' N	129°52' E	19 May 1924	2	60, 80	S (SJ or YF)	Kishinouye (1924)
29°50' N	129°10' E	17 May 1951	3	72-123	S (SJ)	Hotta (1953)
29°47' N	129°25' E	14 Apr. 1924	1	26	S (SJ)	Kishinouye (1926)
29°47' N	129°25' E	21 May 1924	3	63-85	S (SJ or YF)	Kishinouye (1924)
Ryukyu Islands area		early June 1924	2	120, 153	S (SJ or YF)	Kishinouye (1924)
Ryukyu Islands area		July 1923	2	105, 125	S (SJ or YF)	Kishinouye (1924)
Ryukyu Islands area		Aug. 1923	1	210	S (SJ or YF)	Kishinouye (1924)
Satsunan Sea, Tokara area		May 1950-52	1	128	S (SJ)	Hotta & Ogawa (1955)
29°33' N	129°38' E	30 Oct. 1951	5	140-180	S (SJ)	Hotta (1953)
29°30' N	174°19' E	Mar. 1949-50	1	240	S (BE)	Suda (1953)
29°19' N	174°49' E	Mar. 1949-50	1	300	S (BM)	Suda (1953)
29°05' N	127°50' E	12 May 1952	2	65	S (SJ)	Hotta (1953)
28°10' N	129°15' E	16 May 1924	1	58	S (SJ or YF)	Kishinouye (1924)
27°30' N	150°21' E	Feb. 1949-50	1	300	S (BM)	Suda (1953)
26°43' N	126°31' E	19 June 1952	13	80-112	S (SJ)	Hotta (1953)
Ryukyu Islands area (Okinawa)		Aug. 1916	1	210	?	Kishinouye (1923)
Satsunan Sea, Okinawa area		May 1950-52	11	20-154	S (SJ)	Hotta & Ogawa (1955)
Satsunan Sea, Okinawa area		July 1950-52	1	<80	S (SJ)	Hotta & Ogawa (1955)
26°25' N	126°25' E	17 June 1952	5	67-85	S (SJ)	Hotta (1953)
26°13' N	126°29' E	9 June 1937	2	87, 110	S (SJ)	Hotta (1953)
25°30' N	152°07' E	Feb. 1949-50	1	300	S (BM)	Suda (1953)
25°18' N	141°10' E	Dec. 1949-50	1	100	S (BkM)	Suda (1953)
25°17' N	156°51' E	Apr. 1949-50	1	170	S (BM)	Suda (1953)
25°07' N	160°50' E	Apr. 1949-50	1	125	S (BkM)	Suda (1953)

Explanation of footnotes at end of table.

Table I. Pacific Ocean records of collection of juvenile skipjack tuna (*Katsuwonus pelamis*). (con.)

Location of collection[1]		Date	Number collected	Total or fork length (mm)[2]	Method of collection[3]	Reference or collector
Latitude	Longitude					
25°03.5' N	153°47' E	Apr. 1949-50	1	135	S (BM)	Suda (1953)
24°57' N	156°53' E	Apr. 1949-50	2	114, 120	S (BkM)	Suda (1953)
24°53' N	156°58' E	Apr. 1949-50	8	100-275	S (BM)	Suda (1953)
24°53' N	156°53' E	Apr. 1949-50	5	80-300	S (BE, BM, BkM)	Suda (1953)
Bonin Islands area (Iwo Jima)		16-20 Sept. 1951	1	65	S (SJ)	Hotta & Ogawa (1955)
Bonin Islands area (Iwo Jima)		22 Oct. 1951	1	49	S (SJ)	Hotta & Ogawa (1955)
24°34' N	143°49' E	June 1949-50	4	100-130	S (BkM)	Suda (1953)
24°30' N	144°15' E	Apr. 1949-50	3	100-125	S (BE, BM)	Suda (1953)
24°26' N	143°52' E	June 1949-50	4	210-240	S (YF, BM)	Suda (1953)
24°16' N	144°39' E	June 1949-50	3	230-250	S (BM, BkM)	Suda (1953)
24°00' N	143°56' E	Apr. 1949-50	1	90	S (BM)	Suda (1953)
24°00' N	154°00' E	7 July 1957	1	8.96	D	Sun (1960)
23°58' N	145°23' E	June 1949-50	1	200	S (BkM)	Suda (1953)
23°44' N	143°01' E	20 Aug. 1953	1	190	S (SJ)	Hotta & Ogawa (1955)
23°38' N	146°23' E	Apr. 1949-50	2	200	S (BM)	Suda (1953)
23°10' N	145°40' E	Mar. 1949-50	1	200	S (BM)	Suda (1953)
23°00' N	145°50' E	Mar. 1949-50	1	125	S (BM)	Suda (1953)
22°58' N	152°48' E	June 1949-50	1	95	S (BkM)	Suda (1953)
22°56' N	148°52' E	June 1949-50	3	110-200	S (BkM)	Suda (1953)
22°53' N	148°59' E	May 1949-50	2	230, 240	S (BM)	Suda (1953)
22°53' N	148°59' E	June 1949-50	6	82-250	S (BkM)	Suda (1953)
22°50' N	152°42' E	June 1949-50	15	105-210	S (BkM)	Suda (1953)
22°47' N	152°54' E	July 1949-50	3	125-150	S (BkM)	Suda (1953)
22°45' N	141°50' E	19 Aug. 1953	1	172	S (SJ)	Hotta & Ogawa (1955)
22°37' N	144°53' E	Mar. 1949-50	1	123	S (BM)	Suda (1953)
22°28' N	152°40' E	June 1949-50	25	90-265	S (BkM)	Suda (1953)
22°02' N	150°20' E	Mar. 1949-50	1	80	S (BM)	Suda (1953)
21°56' N	152°06' E	July 1949-50	11	105-280	S (BkM)	Suda (1953)
20°44' N	124°47' E	26 Aug. 1951	2	?	S (SJ)	Hotta (1953)
19°46' N	149°46' E	May 1949-50	1	100	S (BkM)	Suda (1953)
19°19' N	148°53' E	May 1949-50	2	70, 80	S (BM, BkM)	Suda (1953)
19°09' N	151°59' E	May 1949-50	1	220	S (BkM)	Suda (1953)

Explanation of footnotes at end of table.

Table I. Pacific Ocean records of collection of juvenile skipjack tuna (Katsuwonus pelamis). (con.)

Location of collection[1] Latitude	Longitude	Date	Number collected	Total or fork length (mm)[2]	Method of collection[3]	Reference or collector
18°56' N	150°52' E	May 1949-50	1	200	S (BkM)	Suda (1953)
18°38' N	151°26' E	May 1949-50	2	100, 150	S (BkM)	Suda (1953)
18°35' N	151°50' E	May 1949-50	2	80, 150	S (YF)	Suda (1953)
18°35' N	151°38' E	May 1949-50	4	120-240	S (BkM)	Suda (1953)
18°26' N	151°40' E	May 1949-50	4	250-300	S (BkM)	Suda (1953)
18°20' N	152°02' E	May 1949-50	4	120	S (BkM)	Suda (1953)
18°18' N	151°28' E	May 1949-50	2	200, 300	S (BkM)	Suda (1953)
*Near Bikini Atoll, Marshall Islands		24 July 1947	2	45, 50	S (SJ)	Marr (1948)
8°21' N	150°42' E	Aug. 1949-50	6	60-165	S (YF, BkM)	Suda (1953)
8°00' N	147°30' E	July 1949-50	20	140-280	S (YF, BkM)	Suda (1953)
7°56' N	162°34' E	Aug. 1949-50	3	190-300	S (BkM)	Suda (1953)
7°50' N	147°25' E	July 1949-50	13	110-250	S (YF, BkM)	Suda (1953)
*Near Truk Islands		3 May 1940	1	45	S (SJ)	Inanami (1942)
6°55' N	146°02' E	July 1949-50	3	100-200	S (BkM)	Suda (1953)
6°37.2' N	121°31' E	7 May 1948	6	13-27	D	Wade (1950)
5°52' N	148°00' E	July 1949-50	9	90-140	S (YF, BkM)	Suda (1953)
5°22' N	164°37' E	Aug. 1949-50	1	130	S (BkM)	Suda (1953)
5°18' N	159°49' E	30 May 1951	12	21-49	D	Matsumoto (1961)
5°03' N	165°53' E	Aug. 1949-50	2	180, 200	S (BkM)	Suda (1953)
5°00' N	150°48' E	Aug. 1949-50	5	120-180	S (YF, BkM)	Suda (1953)
4°52' N	166°40' E	Aug. 1949-50	1	200	S (YF)	Suda (1953)
4°18' N	161°44' E	Aug. 1949-50	2	137, 140	S (YF, BkM)	Suda (1953)
3°35' N	155°00' E	July 1949-50	9	95-150	S (YF, BkM)	Suda (1953)
2°57' N	154°08' E	July 1949-50	4	155-165	S (YF, BkM)	Suda (1953)
2°51' N	157°03' E	25 May 1951	6	23-55	D	Matsumoto (1961)
2°28' N	155°01' E	24 July 1950	2	132, 169	S (SF)	Shimada (1951a)
2°15' N	153°50' E	July 1949-50	3	140-160	S (BkM)	Suda (1953)
2°15' N	154°20' E	July 1949-50	4	70-150	S (BkM)	Suda (1953)
2°12' N	152°12' E	July 1949-50	1	95	S (YF)	Suda (1953)
2°11' N	153°08' E	25 Apr. 1951	5	39-44	D	Matsumoto (1961)
2°09' N	154°11' E	July 1949-50	13	85-200	S (BkM)	Suda (1953)
1°47' N	153°00' E	July 1949-50	2	58, 120	S (YF, BkM)	Suda (1953)
1°42' N	153°16' E	July 1949-50	10	67-165	S (YF)	Suda (1953)
1°31' N	154°09' E	July 1949-50	1	180	S (BkM)	Suda (1953)
1°30' N	154°08' E	21 July 1950	1	130	S (BkM)	Shimada (1951a)

Explanation of footnotes at end of table.

Table I. Pacific Ocean records of collection of juvenile skipjack tuna (Katsuwonus pelamis). (con.)

Location of collection[1] Latitude	Longitude	Date	Number collected	Total or fork length (mm)[2]	Method of collection[3]	Reference or collector
1°25' N	153°14' E	July 1949-50	5	90-145	S (YF, BkM)	Suda (1953)
1°16' N	153°27' E	July 1949-50	2	155, 170	S (BkM)	Suda (1953)
1°14' N	153°00' E	July 1949-50	2	110, 125	S (YF, BkM)	Suda (1953)
1°14' N	157°28' E	8 Aug. 1950	2	132, 148	S (YF)	Shimada (1951a)
1°13' N	150°11' E	Aug. 1949-50	2	110, 180	S (YF, BkM)	Suda (1953)
1°10' N	157°29' E	4 Aug. 1950	2	81, 94	S (YF)	Shimada (1951a)
1°07.5' N	150°17' E	Aug. 1949-50	2	120, 125	S (YF)	Suda (1953)
0°04'3" S	171°53'2" E	6 Feb. 1958	1	5.84	T (Sav)	Sun (1960)
Central Pacific						
21°25.9' N	158°18' W	11 Aug. 1964	2	?	T (Cobb)	W. M. Matsumoto
20°47' N	157°28' W	22 May 1959	1	49	B	Matsumoto (1961)
20°35' N	157°32' W	9 Apr. 1953	1	18	T (1-m)	King & Iversen (1962)
20°30' N	158°45' W	13 July 1948	6	113-118	S (SJ)	Eckles (1949)
Vicinity of Oahu, Hawaiian Islands		13 Aug. 1959	6	? (30-73)	S (SJ)	Matsumoto (1961)
19°39' N	156°13' W	20 Aug. 1964	1	?	T (Cobb)	W. M. Matsumoto
19°39' N	156°13' W	21 Aug. 1964	3	?	T (Cobb)	W. M. Matsumoto
19°33' N	156°00' W	3 Sept. 1948	1	183	S (SJ)	Eckles (1949)
12°13' N	149°56' W	7 Nov. 1958	1	6.8	T (Nan)	Matsumoto (1961)
8°10' N	178°07' W	13 Oct. 1963	1	36.0 (SL)	D	H. O. Yoshida, W. M. Matsumoto
7°39' N	150°16' W	6 Nov. 1958	1	24.1	T (Nan)	Matsumoto (1961)
6°20.5' N	162°22' W	5 Feb. 1956	5	45-58	D	Matsumoto (1961)
6°20.5' N	162°22' W	3 May 1951	34	20-34	D	Matsumoto (1961)
6°06' N	150°28' W	5 Nov. 1958	1	? (14.6-22.6)	T (Nan)	Matsumoto (1961)
5°58' N	173°32'53" W	27 Nov. 1957	1	22.8	T (Sav)	Matsumoto (1961)
5°56' N	139°26' W	21 June 1952	1	18	T (6 ft)	King & Iversen (1962)
3°28' N	157°43' W	26 Jan. 1966	3	24-31	T (Nan)	B. E. Higgins, W. M. Matsumoto
2°56' N	150°03' W	4 Nov. 1958	1	13.9	T (Nan)	Matsumoto (1961)
2°01.5' N	171°37' W	20 June 1951	4	? (16-19)	D	Matsumoto (1961)
0°53' N	140°02' W	31 May 1952	1	19.0	P	Matsumoto (1958)
0°02' N	159°50' W	26 Sept. 1956	1	22	T (IKMT)	King & Iversen (1962)
0°37' S	149°58' W	3 Nov. 1958	3	19.9-21.7	T (Nan)	Matsumoto (1961)
0°44' S	149°46' W	2 Nov. 1958	4	18.5-52.5	T (Nan)	Matsumoto (1961)

Explanation of footnotes at end of table.

Table I. Pacific Ocean records of collection of juvenile skipjack tuna (Katsuwonus pelamis). (con.)

Location of collection[1/] Latitude	Longitude	Date	Number collected	Total or fork length (mm)[2/]	Method of collection[3/]	Reference or collector
2°09' S	149°47' W	2 Nov. 1958	3	23-29	T (Nan)	Matsumoto (1961)
2°59' S	167°51' W	15 Feb. 1966	1	14	T (Nan)	B. E. Higgins, W. M. Matsumoto
3°50.5' S	171°48.5' W	18 July 1950	2	35, 48	D	Shimada (1951b)
4°00' S	172°06' W	2 Mar. 1951	4	5.1-20.1	P	Matsumoto (1958)
4°30' S	172°11' W	5 Aug. 1950	3	20-36	D	Shimada (1951b)
4°57' S	172°36' W	4 Dec. 1957	7	27.6-47.5	D	Sun (1960)
4°58' S	150°00' W	30 Oct. 1958	12	14.5-26	T (Nan)	Matsumoto (1961)
5°00' S	149°58' W	1 Nov. 1958	7	10-30	T (Nan)	Matsumoto (1961)
5°57' S	157°24' W	31 Jan. 1966	1	40	T (Nan)	B. E. Higgins, W. M. Matsumoto
5°57' S	167°47' W	14 Feb. 1966	1	12	T (Nan)	B. E. Higgins, W. M. Matsumoto
7°42' S	140°10' W	28 Feb. 1958	3	? (31-52)	S (YF)	Matsumoto (1961)
8°49' S	140°04.5' W	27 Jan. 1958	7	23.5-34	S (YF)	Matsumoto (1961)
23°17' S	174°46'54" W	26 Dec. 1957	1	96	T (535 cm)	Sun (1960)
Eastern Pacific						
9°22.5' N	85°47.5' W	28 Jan. 1947	1	21	D	Schaefer & Marr (1948)
9°10' N	85°20' W	20 Mar. 1947	1	44	D	Schaefer & Marr (1948)
7°12.5' N	95°52.5' W	11 May 1958	1	18	D	Klawe (1963)
0°23' S	80°50' W	18 Apr. 1958	6	11.5-17.0	D	Klawe (1963)
0°45' S	80°41' W	17 Apr. 1958	1	13	D	Klawe (1963)
*Near Galápagos Islands		? July 1957-Dec. 1959	1	?	S (YF)	Alverson (1963)

[1/] Collections are grouped into three areas: (1) "Western Pacific" (long. 120° E to 180°), (2) "Central Pacific" (long. 180° to 120° W), and (3) "Eastern Pacific" (long. 120° W to west coast of the Americas). Collections are listed in each general area according to latitude, from the northernmost to the southernmost record. Each collection for which I estimated a position for the distributional map (fig. 1) is denoted by an asterisk (*). General areas without asterisks are not represented on fig. 1.

[2/] Ranges of length that include more than one species are given in parentheses preceded by a question mark; SL = standard length.

[3/] B = tuna bait seine, D = dip net, P = plankton net. For collections from stomachs (S), the predator is shown in parentheses: BE = bigeye tuna, BM = blue marlin, BkM = black marlin, SF = sailfish, SJ = skipjack tuna, YF = yellowfin tuna. The various kinds of midwater trawls (T) are indicated in parentheses: Cobb = Cobb pelagic trawl, IKMT = 10-ft. Isaacs-Kidd midwater trawl, Nan = Nanaimo net, Sav = Savilov's net, 1-m = 1-m ring trawl, 6 ft. = 6-ft. beam trawl, 535 cm = 535-cm diameter conical net.

Juvenile skipjack tuna are apparently absent in the vast expanse of ocean between the Hawaiian, Line, Marquesas, and Tuamotu Islands in the Central Pacific and the west coast of the Americas. To judge from the scarcity of larval skipjack tuna as compared with larval yellowfin tuna in the same area (Matsumoto, in press), this absence may be real. But in this area, as in many others, the effort to collect juveniles must be intensified before meaningful conclusions can be drawn.

Juvenile yellowfin tuna

In the western and central Pacific, juvenile yellowfin tuna have been collected in about the same general area as skipjack tuna, but much less frequently (Table II, Fig 2). They are known to occur as far north as approximately lat. 31° N near Japan and lat. 23° N near Hawaii. There are two records from as far south as lat. 23° S. In the central tropical Pacific, yellowfin tuna have been reported only from two locations at about lat. 2° and 6° N.

In the eastern Pacific, the northernmost record for juvenile yellowfin tuna is from about lat. 24° N, just off Baja California. No juveniles are recorded from farther south of the Equator than about lat. 2° S, just off the coast of Ecuador. I found no records of juvenile yellowfin tuna from the area between long. 150° W and 112° W, but this hiatus probably again reflects to some degree the relatively limited sampling effort in this area. Larvae of yellowfin tuna have been taken throughout this region, as well as around the Marquesas and Tuamotu Islands (Matsumoto, in press).

Juvenile albacore

There are few records of juvenile albacore from the Pacific Ocean, and most of these are from stomachs of tunas and billfishes caught at high latitudes (Table III, Fig 2). Yabe et al. (1958) found five juvenile albacore in the stomachs of yellowfin tuna and billfishes caught in subtropical waters near the Marianas Islands, Fiji Islands, and just east of Australia. Yoshida (1965) identified five albacore from stomachs of billfishes caught near Hawaii, and seven from stomachs of fish caught near the Ellice and Fiji Islands. In August and September 1963 several young albacore (25-43 cm) were taken by live-bait fishing in the northeastern sea are of Japan (Asano, 1964).

Insofar as I can determine, there is no record of collection of juvenile albacore in the eastern Pacific. Otsu and Uchida (1963) mentioned, however, that albacore of about 35 cm appeared in the American fishery during the summer of 1954.

Juvenile bigeye tuna

Records of capture of juvenile bigeye tuna are extremely rare (Table IV, Fig. 2). In the western Pacific, Marukawa mentioned finding small bigeye tuna in stomachs of yellowfin tuna caught in the Palau Islands area (Hatai et al., 1941). Juvenile bigeye tuna have also been removed from stomachs of fish caught northwest of Australia and near the Philippine Islands (Yabe et al., 1958).

Table II. Pacific Ocean records of collection of juvenile yellowfin tuna (Thunnus albacares).

Location of collection[1]						
Latitude	Longitude	Date	Number collected	Total or fork length (mm)[2]	Method of collection[3]	Reference or collector
Western Pacific						
31°17' N	131°46' E	29 Oct. 1952	1	195 (SL)	S (YF)	Yabe et al (1958)
Gonsone, Ryukyu Islands		26 May 1925	1	63	S (SJ)	Kishinouye (1926)
29°30' N	129°05' E	10 May 1924	1	100	S (SJ)	Kishinouye (1926) (identification uncertain)
18°00' N	153°52' E	23 July 1952	1	130 (SL)	S (SNS)	Yabe et al (1958)
11°05'8" N	139°58'6" E	20 May 1958	1	6.6	T (Sav)	Sun (1960)
*9-10° N	176-177° E	Feb. 1953	1	ca 140 (SL)	S (BkM)	Yabe et al (1958)
**5-8° N	133-134° E	Oct. 1957	4	ca 170-195 (SL)	S (BkM)	Yabe et al (1958)
6°44.5' N	125°36.7' E	13 May 1948	13	9.8-35	D	Wade (1950)
6°37.2' N	121°31' E	7 May 1948	5	14-20	D	Wade (1950)
6°33.5' N	138°57' E	1 Dec. 1958	2	ca 200	S	S. Ueyanagi
3°45' N	140°17' E	26 Nov. 1958	1	ca 100	S	S. Ueyanagi
10°07' S	121°26' E	21 Feb. 1953	1	147 (SL)	S (WM)	Yabe et al (1958)
15°54' S	146°15' E	22 Nov. 1956	1	107 (SL)	S (WM)	Yabe et al (1958)
23°29' S	170°39' E	26 Feb. 1958	1	12.04	T (Sav)	Sun (1960)
Central Pacific						
23°18' N	163°00' W	16 Aug. 1948	3	216-219	G	Greenhood (1952)
*Near Oahu, Hawaiian Islands		13 Aug. 1959	1	? (30-73)	S (SJ)	Matsumoto (1961)
6°06' N	150°28' W	5 Nov. 1958	2	? (14.6-22.6)	T (Nan)	Matsumoto (1961)
2°01.5' N	171°37' W	20 June 1951	2	? (16-19)	D	Matsumoto (1961)
23°17' S	174°47' W	26 Dec. 1957	5	5.25-8.52	T (535 cm)	Sun (1960)
Eastern Pacific						
23°48' N	112°02' W	4 Nov. 1956	1	29	D	Klawe (1963)
18°30' N	104°30' W	May 1959	2	35, 40	S (YF)	Klawe (1963)
*Near Revillagigedo Islands			3	?	S (YF)	Alverson (1963)
18°00' N	105°47' W	28 June 1941	2	31, 135	D	Klawe (1959)

Explanation of footnotes at end of table.

Table II. Pacific Ocean records of collection of juvenile yellowfin tuna (Thunnus albacares). (con.)

Location of collection[1] Latitude	Longitude	Date	Number collected	Total or fork length (mm)[2]	Method of collection[3]	Reference or collector
13°33' N	92°43' W	12 Sept. 1960	16	9.5-15.5	D	Klawe (1963)
12°39' N	91°40' W	5 Apr. 1957	1	11	D	Klawe (1963)
12°34' N	91°38' W	4 Apr. 1957	1	12	D	Klawe (1963)
12°16' N	89°31' W	17 May 1949	25	15.5-25.0	D	Mead (1951)
12°11' N	90°18' W	30 May 1949	5	19.5-26.5	D	Mead (1951)
12°08' N	88°18' W	8 Aug. 1960	2	16.5, 17.0	D	Klawe (1963)
11°05' N	89°55' W	28 May 1949	12	10.5-16.0	D	Mead (1951)
10°20' N	86°20' W	20 May 1958	23	7-11	D	Klawe (1963)
*10 mi. west of Cape Blanco, Costa Rica		5-6 June 1959	1	18	D	Klawe (1963)
*5 mi. southeast of Cape Blanco, Costa Rica		9-10 Apr. 1959	2	12, 14	D	Klawe (1963)
*10 mi. southeast of Cape Blanco, Costa Rica		6-7 May 1959	3	12-16	D	Klawe (1963)
*10 mi. south of Cape B Blanco, Costa Rica		22 Jan. 1960	8	10-14	D	Klawe (1963)
*10 mi. south of Cape Blanco, Costa Rica		30 Mar. 1960	7	7-31	D	Klawe (1963)
*10 mi. south of Cape Blanco, Costa Rica		21 Sept. 1960	22	11.0-11.5	D	Klawe (1963)
*10 mi. south of Cape Blanco, Costa Rica		21 Oct. 1960	7	10.5-30.0	D	Klawe (1963)
9°22.5' N	85°47.5' W	28 Jan. 1947	2	14, 15	D	Schaefer & Marr (1948)
*15 mi. south southeast of Cape Blanco, Costa Rica		25 Feb. 1960	5	11.5-13.0	D	Klawe (1963)
9°20' N	85°10' W	1 Apr. 1947	20	10-24	D	Schaefer & Marr (1948)
*15 mi. south of Cape Blanco, Costa Rica		26-27 Dec. 1958	1	27	D	Klawe (1963)
*20 mi. south southwest of Cape Blanco, Costa Rica		24 Feb. 1960	54	11-26	D	Klawe (1963)
*20 mi. south of Cape Blanco, Costa Rica		11-12 Feb. 1959	2	23, 24	D	Klawe (1963)
*20 mi. south of Cape Blanco, Costa Rica		29 Mar. 1960	2	22, 29	D	Klawe (1963)

Explanation of footnotes at end of table.

Table II. Pacific Ocean records of collection of juvenile yellowfin tuna (*Thunnus albacares*). (con.)

Location of collection[1] Latitude	Longitude	Date	Number collected	Total or fork length (mm)[2]	Method of collection[3]	Reference or collector
*20 mi. south of Cape Blanco, Costa Rica		8-9 Apr. 1959	12	16-20	D	Klawe (1963)
*20 mi. south of Cape Blanco, Costa Rica		26-27 Dec. 1958	1	26	D	Klawe (1963)
9°10' N	85°20' W	20 Mar. 1947	6	26-43	D	Schaefer & Marr (1948)
*30 mi. south of Cape Blanco, Costa Rica		20 Oct. 1960	10	13-21	D	Klawe (1963)
8°45' N	83°55' W	June 1938	8	ca 50	S (PP)	Klawe (1963)
8°12' N	83°17' W	5 Apr. 1959	1	12	D	Klawe (1963)
8°07.5' N	83°08.5' W	7 May 1947	1	41	D	Schaefer & Marr (1948)
7°30' N	82°30' W	12 Apr. 1959	1	37	D	Klawe (1963)
5°30' N	86°57' W	3 Dec. 1959	7	11.5-16	D	Klawe (1963)
0°23' S	80°50' W	18 Apr. 1958	8	11-18	D	Klawe (1963)
0°45' S	80°41' W	17 Apr. 1958	1	16	D	Klawe (1963)
2°12' S	81°11' W	22 Apr. 1958	1	11.5	D	Klawe (1963)

[1] Collections are grouped into three areas: (1) "Western Pacific" (long. 120° E to 180°), (2) "Central Pacific" long. 180° to 120° W), and (3) "Eastern Pacific" (long. 120° W to west coast of the Americas). Collections are listed in each general area according to latitude, from the northernmost to the southernmost record. Each collection for which I estimated a position(s) for the distributional map (fig. 2) is denoted by an asterisk(s) (*).

[2] Ranges of length that include more than one species are given in parentheses preceded by a question mark; SL = standard length.

[3] D = dip net, G = gill net. For collection from stomachs (S), the predator is shown in parentheses: BkM = black marlin, PP = *Pelamis platurus*, SJ = skipjack tuna, SNS = shortnose spearfish, WM = white marlin, YF = yellowfin tuna. The various kinds of midwater trawls are indicated in parentheses: Nan = Nanaimo net, Sav = Savilov's net, 535 cm = 535-cm diameter conical net.

Table III. Pacific Ocean records of collection of juvenile albacore (Thunnus alalunga).

Location of collection[1] Latitude	Longitude	Date	Number collected	Standard length (mm)	Method of collection[2]	Reference or collector
Western Pacific						
23°46' N	171°02' E	11 Aug. 1960	2	131	S (BM)	Yoshida (1965)
20°57' N	149°36' E	11 June 1952	1	124	S (BkM)	Yabe et al. (1958)
18°38' N	151°26' E	15 May 1949	1	188	S (BkM)	Yabe et al. (1958)
10°43' S	178°46' E	25 Feb. 1962	1	85	S (BM)	Yoshida (1965)
18°44' S	176°54' E	1 Feb. 1955	1	ca 170	S (YF)	Yabe et al. (1958)
18°58' S	176°27' E	2 Feb. 1955	1	ca 170	S (YF)	Yabe et al. (1958)
20°50' S	155°30' E	6 Dec. 1956	1	234	S (SM)	Yabe et al. (1958)
Central Pacific						
*Off Waianae, Oahu, Hawaiian Islands		13 Aug. 1962	1	135	S (SM)	Yoshida (1965)
*Off Waianae, Oahu, Hawaiian Islands		13 Sept. 1962	1	184	S (BM)	Yoshida (1965)
*Off Waianae, Oahu, Hawaiian Islands		2 Nov. 1962	2	257, 283	S (SM)	Yoshida (1965)
*Off Kona, Hawaii, Hawaiian Islands		1 Aug. 1962	1	184	S (BM)	Yoshida (1965)
6°32' S	162°45' W	24 Mar. 1962	1	74	S (WH)	Yoshida (1965)
13°25' S	179°15' W	26 Feb. 1962	2	61, 75	S (YF)	Yoshida (1965)
15°35' S	171°16' W	13 Mar. 1962	1	88	S (BM)	Yoshida (1965)
19-26° S	128-139° W	Feb.-Mar. 1958	2	157.5, 204(TL)[3]	S	S. Ueyanagi

[1] Collections are grouped into two areas: (1) "Western Pacific" (long. 120° E to 180°) and (2) "Central Pacific" (long. 180° to 120° W). Collections are listed in each general area according to latitude, from the northernmost to the southernmost record. Each collection for which I estimated a position for the distributional map is denoted by an asterisk (*). General areas without asterisks are not represented on figure 2.

[2] For collections from stomachs (S), predators are shown in parentheses: BM = blue marlin, BkM = black marlin, SM = striped marlin, WH = wahoo, YF = yellowfin tuna.

[3] Total or fork length.

Table IV. Pacific Ocean records of collection of juvenile bigeye tuna (Thunnus obesus).

Location of collection[1/] Latitude	Longitude	Date	Number collected	Standard length (mm)	Capture method[2/]	Reference or collector
Western Pacific						
**5-8° N	133-134° E	Oct. 1957	1	ca 195	S (BkM)	Yabe et al. (1958)
*Tokobei area, Palau Island		1939 (?)	?	107-109	S (YF)	H. Marukawa (Hatai et al. 1941)
1°16' N	153°27' E	13 July 1950	1	216	S (BkM)	Yabe et al. (1958)
10°07' S	121°26' E	21 Feb. 1953	1	173	S (D)	Yabe et al. (1958)

[1/] Collections are reported from one area, the "Western Pacific" (long. 120° E to 180°). Collections are listed according to latitude, from the northernmost to the southernmost record. Each collection for which I estimated a position(s) for the distributional map (fig. 2) is denoted by an asterisk(s) (*).

[2/] S = stomach, YF = yellowfin tuna, BkM = black marlin, D = dolphin.

The only reference that I find to juvenile bigeye tuna collected in the central Pacific is in Yabe et al. (1963), who indicated (their Fig. 2) that this species has been found near long. 135° W. Lacking other information, however, I did not include this record in Table IV or Fig. 2. But the occurrence of small bigeye tuna in the central Pacific is not unexpected. Dung and Royce (1953) reported that bigeye tuna 36-50 cm long were taken by pole and line or trolling near the Hawaiian Islands.

There seems to be no record of collection of juvenile bigeye tuna in the eastern Pacific.

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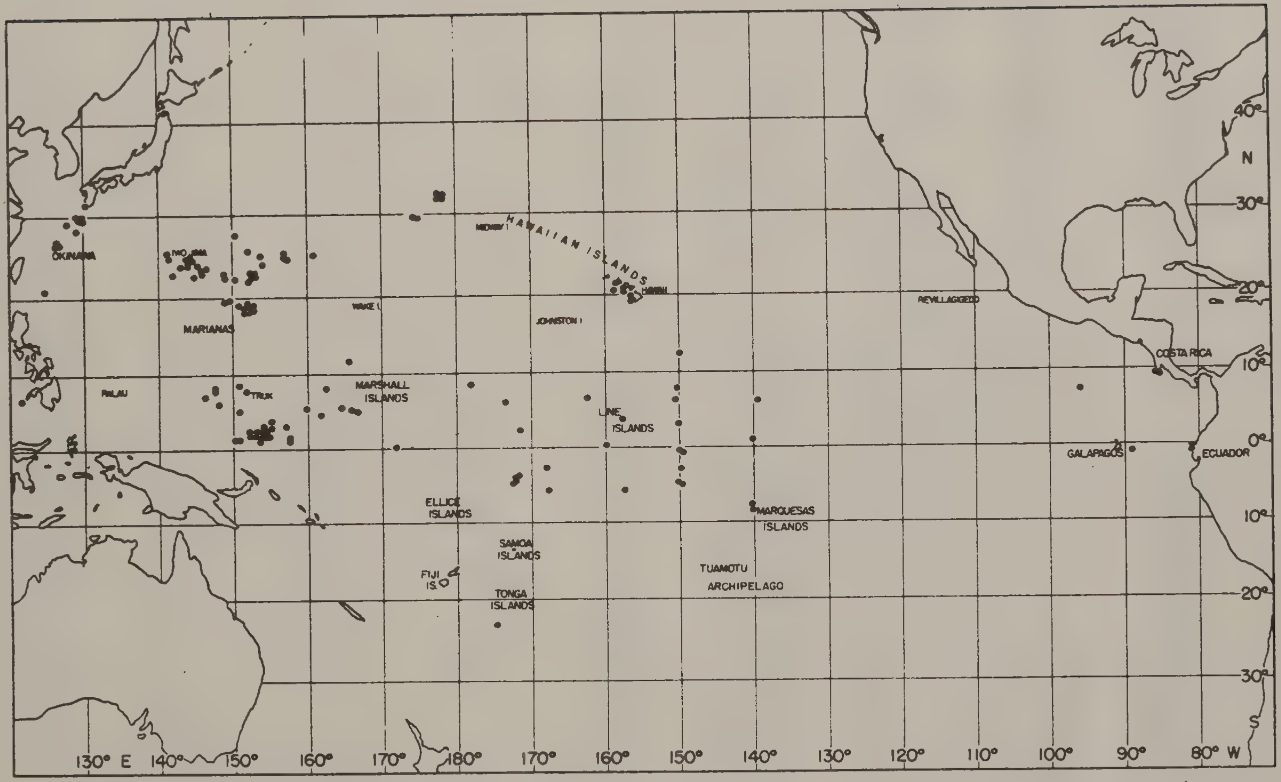
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Fig. 1. Locations of Collection of Juvenile Skipjack Tuna (Katsuwonus pelamis) in the Pacific Ocean, 1916-66

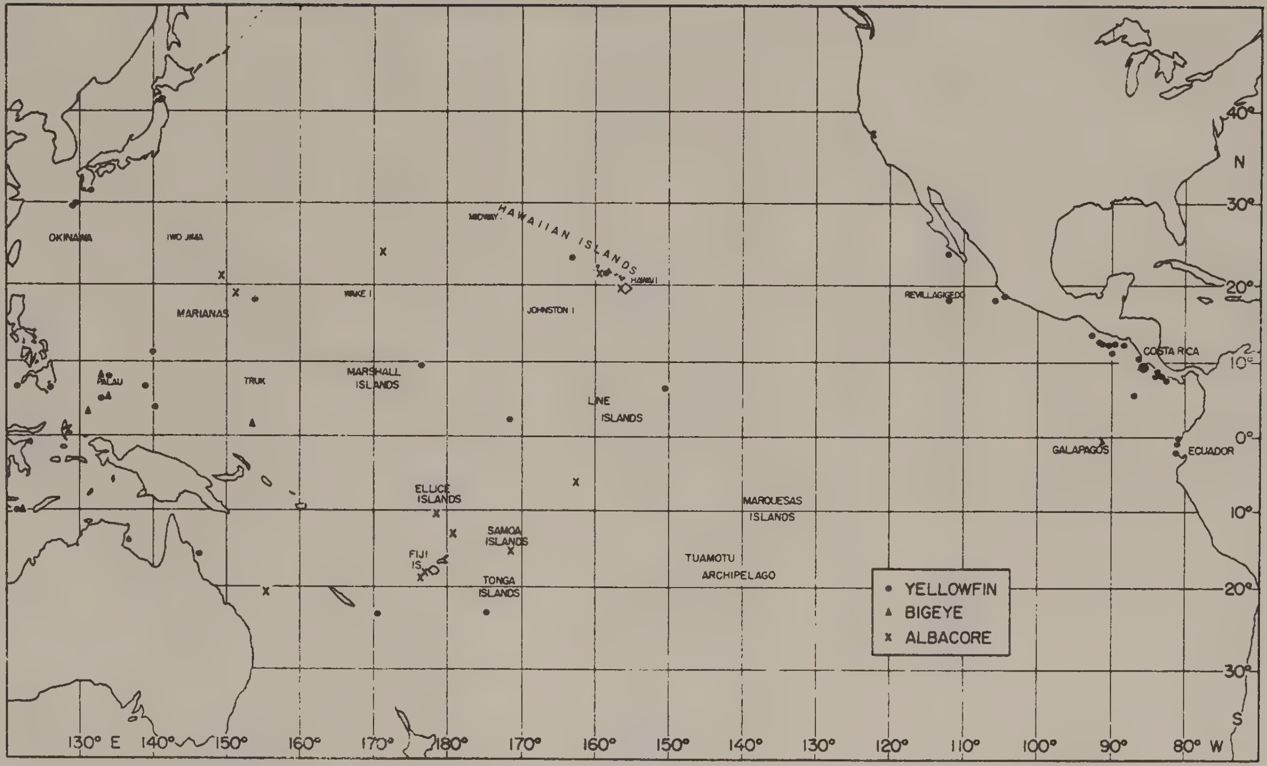
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Fig. 2. Locations of Collection of Juvenile Yellowfin Tuna (Thunnus albacares), Bigeye Tuna (T. obesus), and Albacore (T. alalunga) in the Pacific Ocean, 1916-66

SOME OLIGOCHAETES FROM LAKE MICHIGAN[1, 2]

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ABSTRACT: Twenty-six species of Tubificidae, 12 Naididae, and 1 Lumbriculidae were found in three regions of Lake Michigan—Green Bay, the southern end of the lake proper, and the harbor at Ludington, Michigan. One new naidid species is described. Methods of identification of some species are discussed and illustrated. The abundance of oligochaetes and distribution of certain species vary with depth and location. Data are presented on the effects of the environment on the distribution of certain species. The presence or absence of some species reflected the quality of the environment; some were prevalent in polluted waters whereas others were restricted or absent. Possible changes in composition and abundance of species are outlined if organic enrichment increases in Lake Michigan.

INTRODUCTION

The Oligochaeta, especially the family Tubificidae, form a group of macrobenthos that has gained particular attention in studies of the freshwater environment. Frequently aquatic oligochaetes have been incorrectly assumed to be entirely tubificids. Past publications on Lake Michigan benthos have included this assumption (Eggleton, 1936, 1937; Cook & Powers, 1964). The present work demonstrates that the Oligochaeta of the lake also include Naididae and Lumbriculidae, and that occasionally oligochaetes at some locations include no Tubificidae.

The extent of ecological research on North American aquatic oligochaetes is meager. The deficiency may have been caused by the inadequate taxonomic knowledge of this group. Occasionally faunistic studies have listed some species but in view of past taxonomic inadequacy, the accuracy of some identifications may be questionable. Recent works of Brinkhurst (1963, 1964, 1965) have provided a broader guide to the kinds of naidids and tubificids found in North America. Primarily, Brinkhurst's interpretation of species is followed in this report.

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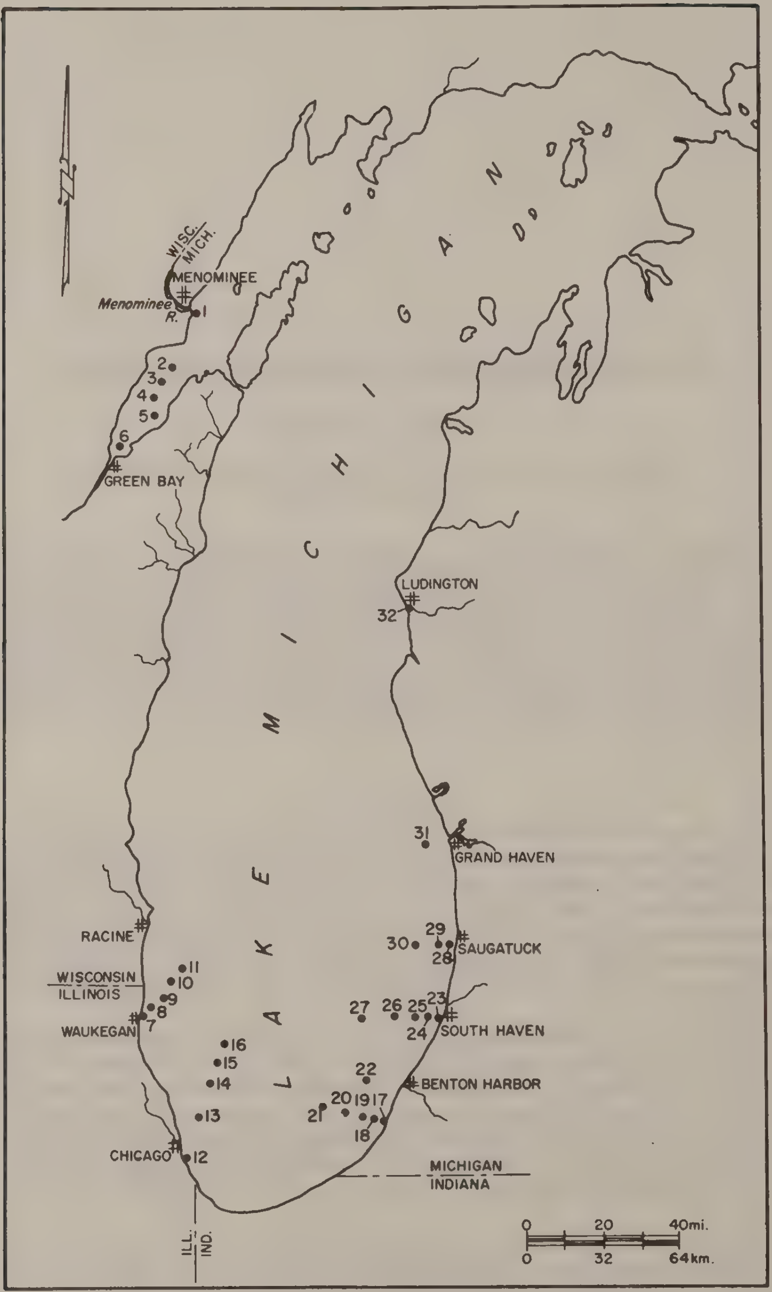
[1] Contribution No. 360, Ann Arbor Biological Laboratory, U. S. Bureau of Commercial Fisheries.

[2] I thank R. O. Brinkhurst for suggestions on taxonomy and review of the manuscript.

TRANS. AMER. MICROSC. SOC. 86(4): 433–454. 1967.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WAUKEGAN
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26
25
23
24
SOUTH HAVEN
16
15
14
22
BENTON HARBOR
20
19
17
21
13
18
CHICAGO
12
MICHIGAN
INDIANA
ILL.
IND.
0 20 40mi.
0 32 64km.

FIG. 1. Location of sampling stations in Lake Michigan.

Some poorly understood species complexes still exist and brief notes and figures are included to aid in the recognition of these complexes and certain difficult species and groups of related species.

The scope of this report is to list some of the more common oligochaetes in southern Lake Michigan, demonstrate their distribution and abundance, and comment on their taxonomy and ecology.

Methods and Materials

Data for this report were assembled from several studies conducted from the R/V *Cisco* during 1960–65. Stations sampled appear in Figure 1. Unless otherwise noted, data for this report are only from samples taken with a Petersen dredge.

All samples were washed through a U. S. Standard no. 30 mesh wire screen (0.5-mm opening) and the residue was preserved in formalin. Oligochaetes were sorted from the 1962 samples with unaided eye, and from all other samples at 15 × magnification. Many specimens were broken when the samples were screened; only those in which the anterior end was intact were counted. Each specimen was prepared for examination by the method described by Brinkhurst (1963). Species identification is based on characteristic configuration of the chaetae and male genitalia illustrated in Figures 2–24 for the difficult groups. The collections included 56,600 specimens. All were examined at a magnification of 35 × or more.

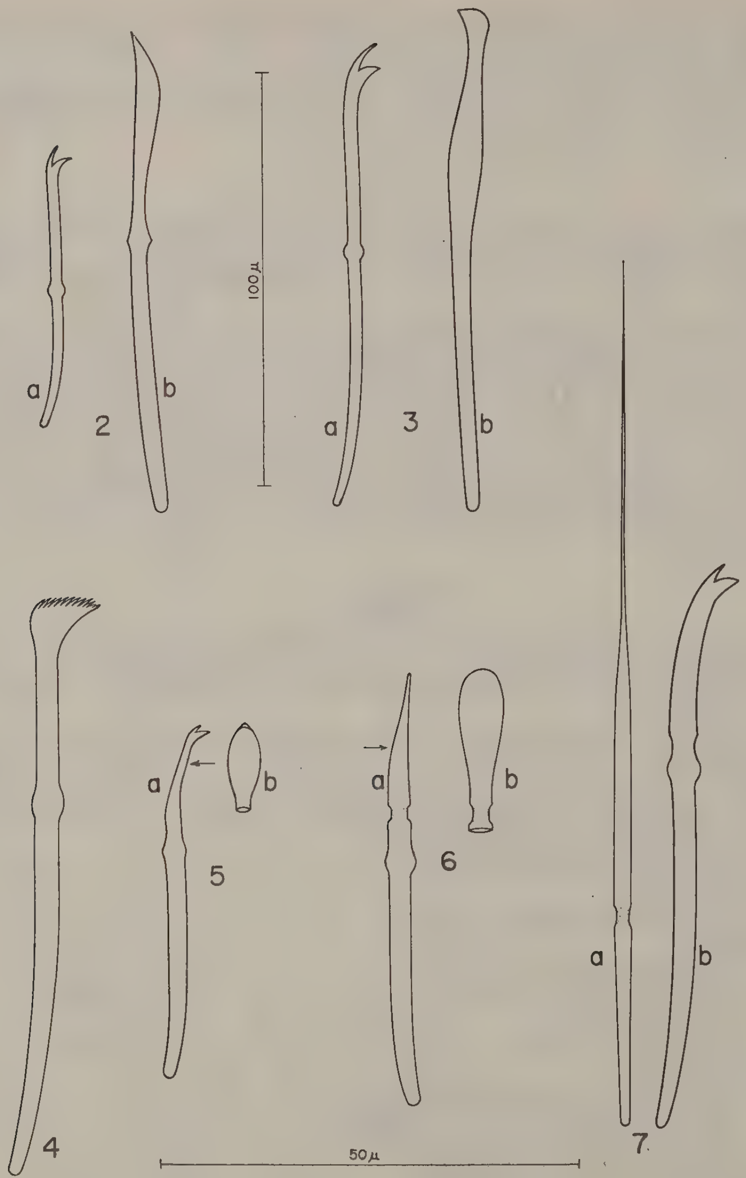
Taxonomy

Twenty-six species of Tubificidae, 12 Naididae, and 1 Lumbriculidae were identified from Lake Michigan. A few specimens of Enchytraeidae seen in some of the samples are not discussed here because the taxonomy of this group is not adequately known.

The species observed include nearly all that are known from fresh waters of northeastern United States and many represent new records for the lake. Identity of the few species previously reported from the lake (Merna, 1960) remains uncertain because the work provided no description or illustration which would help confirm the determinations.

Species found in the present study were:

- Lumbriculidae
    - *Stylodrilus heringianus* Claparède
- Naididae
    - *Amphichaeta* sp.
    - *Arcteonais lomondi* (Martin)
    - *Chaetogaster* sp.
    - *Dero digitata* (Müller)
    - *Nais* sp.
    - *Ophidonais serpentina* (Müller)
    - *Piguetiella michiganensis* Hiltunen
    - *Slavina appendiculata* (d'Udekem)
    - *Specaria josinae* (Vejdovský)
    - *Stylaria lacustris* (Linnaeus)
    - *Uncinais uncinata* (Ørsted)
    - *Vejdovskyella intermedia* (Bretscher)
- Tubificidae
    - *Aulodrilus americanus* Brinkhurst & Cook
    - *A. limnobius* Bretscher
    - *A. pigueti* Kowalewski



FIGS. 2–7. **2**. Lateral aspect of *Piguetiella michiganensis* chaetae: *a*. somatic chaeta, *b*. spermathecal chaeta; **3**. Lateral aspect of *Uncinais uncinata* chaetae: *a*. somatic chaeta of segments II–V, *b*. penial cheta; **4**. *Aulodrilus americanus* chaeta posteriorad of segment X; **5**. *A. limnobius* chaeta posteriorad of segment VIII: *a*. lateral aspect, *b*. ventral (posterior) aspect of tip as viewed from direction of arrow in *a*. **6**. *A. pigueti* dorsal chaeta, posteriorad of segment VII or VIII: *a*. lateral aspect, *b*. dorsal (anterior) aspect of tip as viewed from direction of arrow in *a*; **7**. *A. pluriseta* dorsal chaetae: *a*. capilliform chaeta; *b*. lateral aspect of crotchet.

A. pluriseta (Piguet)
Ilyodrilus templetoni (Southern)
Limnodrilus angustipenis Brinkhurst & Cook
L. cervix Brinkhurst
L. claparedianus Ratzel
L. hoffmeisteri Claparède
L. maumeensis Brinkhurst & Cook
L. profundicola (Verrill)
L. udekemianus Claparède
Peloscolex ferox (Eisen)
P. freyi Brinkhurst
P. multisetosus multisetosus (Smith)
P. multisetosus longidentus Brinkhurst & Cook
P. superiorensis Brinkhurst & Cook
P. variegatus Leidy
Potamothrix bavaricus (Oschmann)
P. hammoniensis (Michaelsen)
P. moldaviensis Vejdovský & Mrázek
P. vejdovskyi (Hrabě)
Rhyacodrilus coccineus (Vejdovský)
R. montanus (Brinkhurst)[3]
Tubifex ignotus (Štolc)
T. kessleri americanus Brinkhurst & Cook
T. tubifex (Müller)

Lumbriculidae

Stylodrilus heringianus was the only species of the family Lumbriculidae identified from Lake Michigan. A few individuals which may not be of this species were found at Station 14, but these were disregarded because sexual immaturity prevented positive determination. *S. heringianus* can be recognized by two chaetae per bundle and especially by the reduced distal tooth of each chaeta. Sexually mature individuals can also be identified by the paired external penes. One anomalous specimen was found with a supernumerary pair of penes (Fig. 25). The counts of *S. heringianus* in this study include individuals in all stages of maturity.

Naididae

Taxonomy of the Naididae is based primarily on external features. Keys work well for most of the species, but descriptions for *Nais* are incomplete for North American material and I have not attempted to identify *Nais* beyond genus. Identification of *Amphichaeta* and *Chaetogaster* is also difficult and the assignment of a trivial name can only be done with uncertainty. There appeared to be only one species each of *Amphichaeta, Chaetogaster*, and *Nais*. Eight other naidids were interpreted according to Sperber (1948, 1950) and Brinkhurst (1964). One new species was discovered.

Piguetiella michiganensis n. sp.

Eyespots absent. All chaetae, both dorsal and ventral, are bifid crotchets, all essentially alike, distal tooth equal to, or shorter and more slender than the proximal (Fig. 2a); length of chaetae in segments II–V ca. 60 μ. Dorsal chaetae

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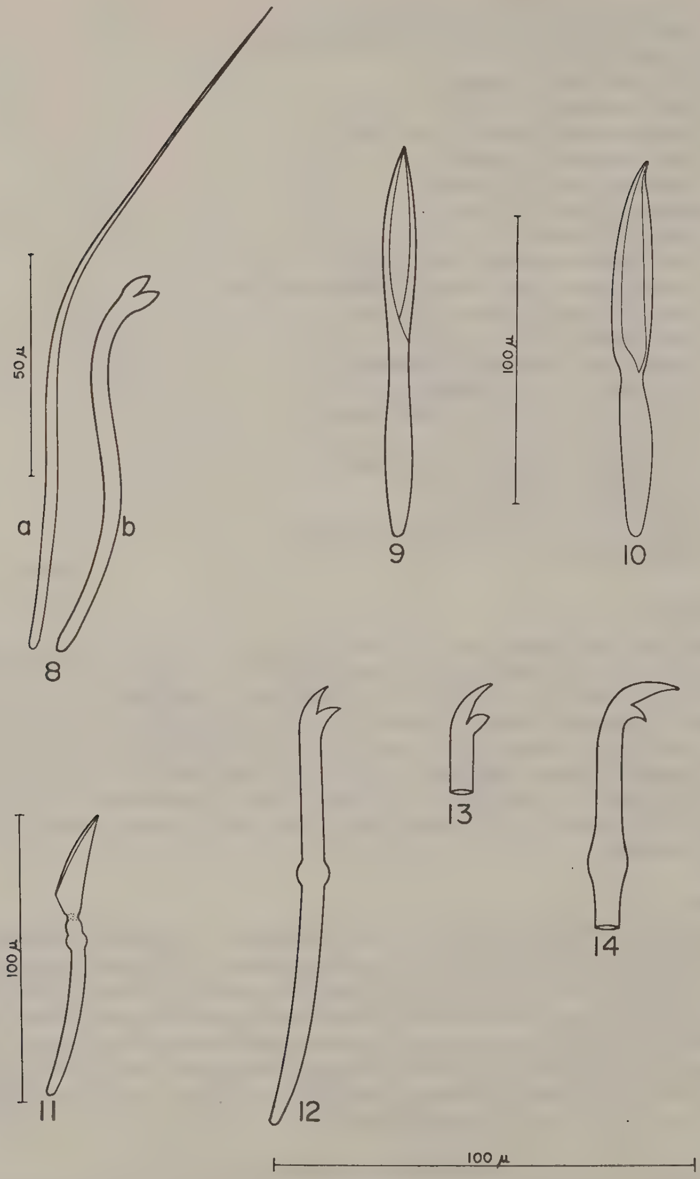
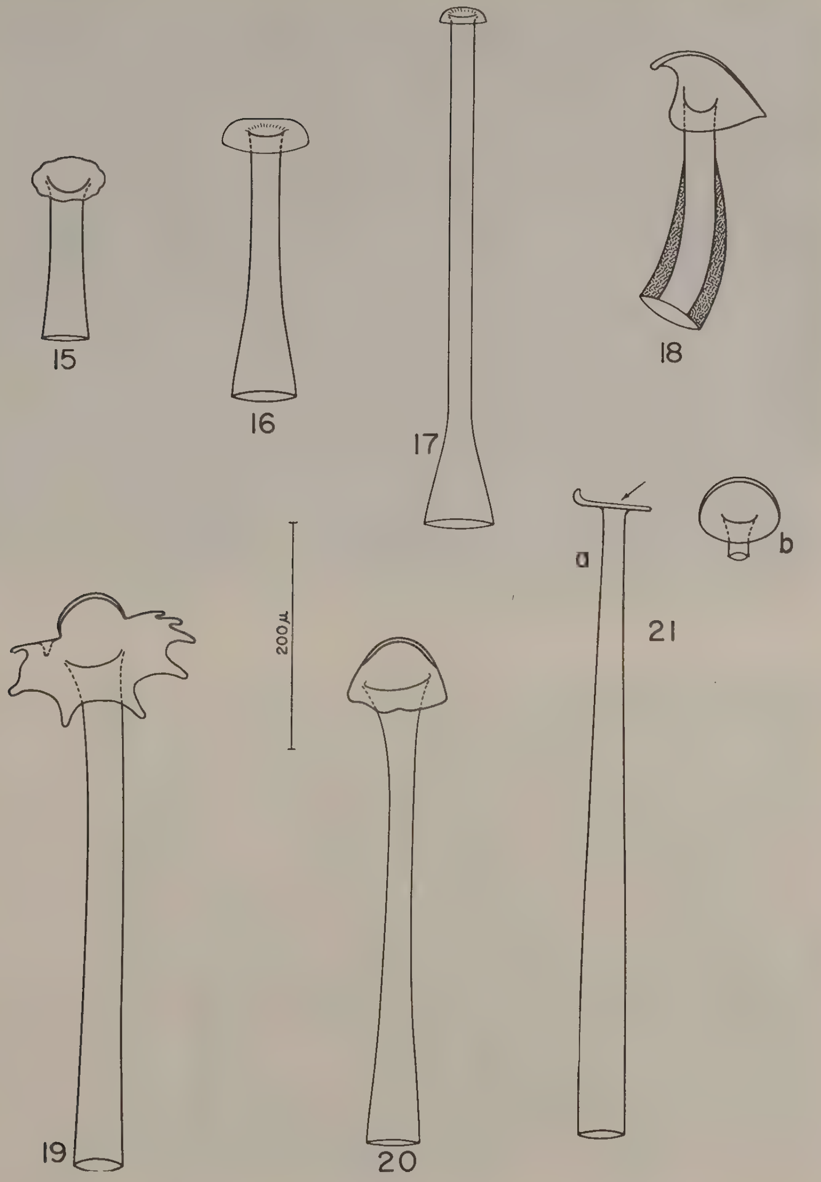
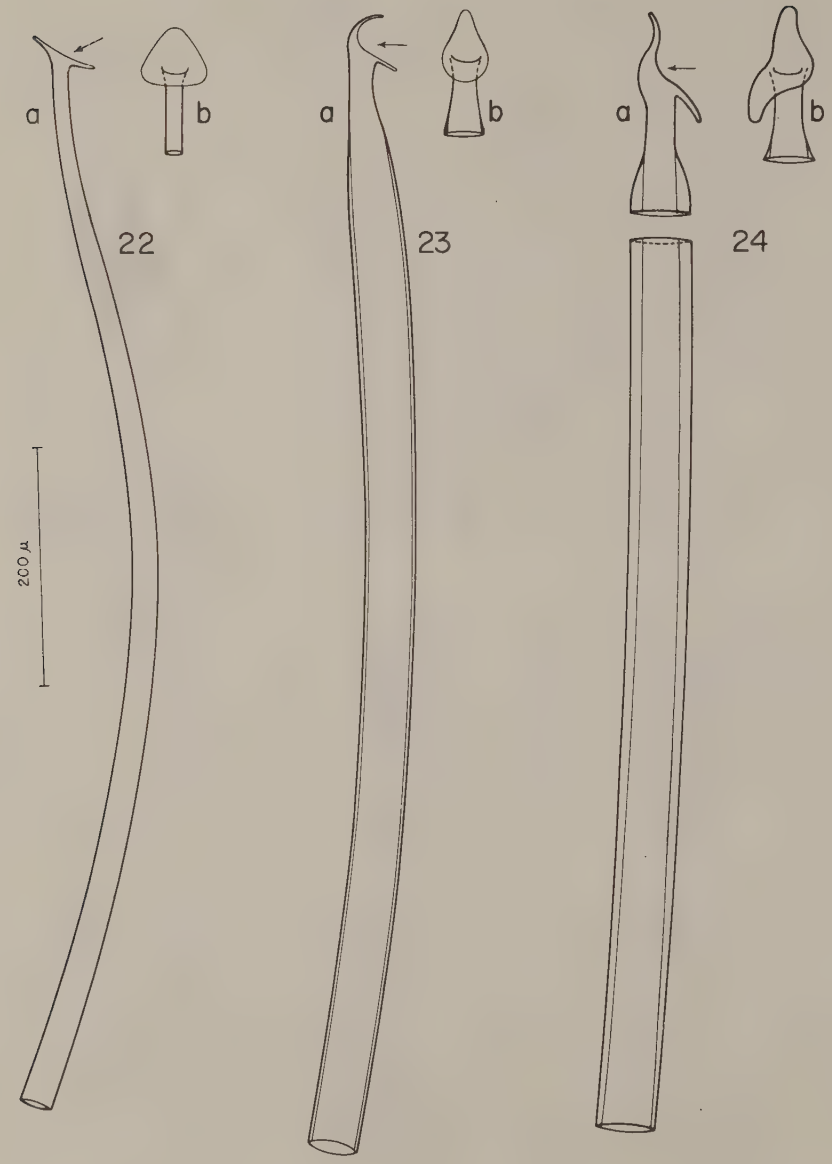
[3] One specimen of this species was found at 36.5 m off Saugatuck, Michigan, October 1966.



FIGS. 8–14. **8**. *Potamothrix vejdovskyi* anterior dorsal chaetae: *a*. *capilliform* chaeta, *b*. dorso-lateral aspect of crotchet; **9**. "Facial" aspect of *P. vejdovskyi* spermathecal chaeta; **10**. "Facial" aspect of *P. moldaviensis* spermathecal chaeta; **11**. "Facial" aspect of *P. bavaricus* spermathecal chaeta; **12**. *Limnodrilus hoffmeisteri* chaeta, lateral aspect; **13**. Tip of *L. hoffmeisteri* (variant) chaeta, lateral aspect; **14**. Distal half of *L. udekemianus* chaeta, lateral aspect.



Figs. 15–21. Penis tubes of *Limnodrilus* species. **15**. *L. udekemianus*; **16**. *L. profundicola*; **17**. *L. angustipenis*; **18**. *L. maumeensis* (distal end); **19**. *L. hoffmeisteri* (variant); **20**. *L. hoffmeisteri* (typical); **21**. *L. hoffmeisteri* (variant): *a*. lateral aspect, *b*. distal end viewed from direction of arrow in *a*.



FIGS. 22–24. Penis tubes of *Limnodrilus* species. **22**. *L. claparedianus*: *a.* lateral aspect, *b.* distal end viewed from direction of arrow in *a*; **23**. *L. cervix* (variant): *a.* lateral aspect, *b.* distal end viewed from direction of arrow in *a*; **24**. *L. cervix* (typical): *a.* lateral aspect, *b.* distal end viewed from direction of arrow in *a.*

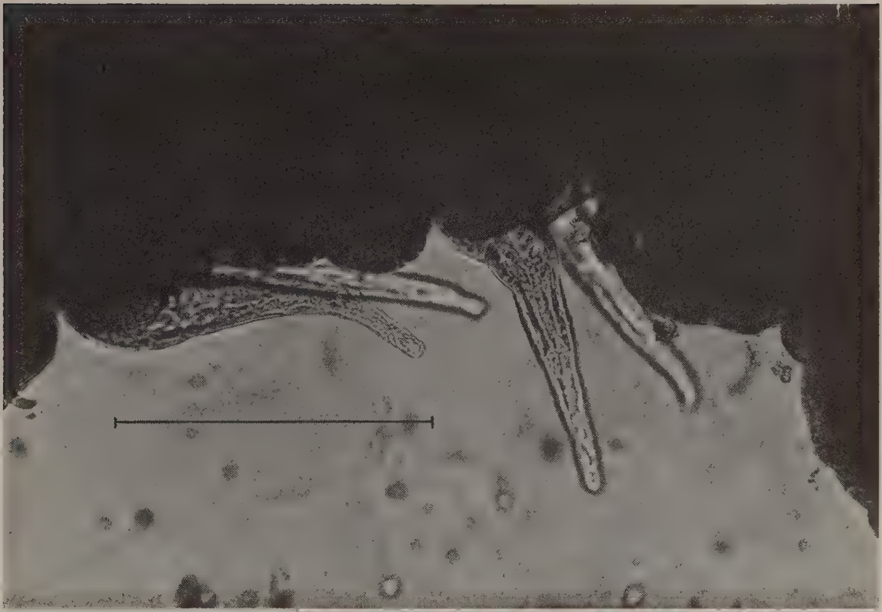


FIG. 25. *Stylodrilus heringianus* bearing an extra pair of external penes (lateral view; partly cleared). Line equals 200 μ.

absent in segments I–V; number of crotchets per bundle varies with size and most likely with age of the individual, up to 11 per ventral bundle in segment II. Individuals which bear a clitellum have fewer chaetae in segment VII than in the succeeding few segments. Paired bundles of one to four blade-like genital chaetae (Fig. 2b) per bundle arise near each spermatheca and are directed ventrad, perpendicular to the long axis of the body; length of the spermathecal chaetae are ca. 115 μ. No modified penial chaetae. Male pores penetrate the clitellum. Pharyngeal and esophageal gland cells present. Coelomocytes present. Body length of sexually mature individual is about 5 mm.

The holotype is deposited in the U. S. National Museum, catalogue no. 35753.

P. michiganensis (Fig. 26) is similar to the European *P. blanci* but can be differentiated from it primarily by the lack of eyespots and by the shape of the paired genital chaetae. *P. blanci* ordinarily has capilliform chaetae in the dorsal bundles but no such chaetae have been found on *P. michiganensis*. Superficially *Uncinais uncinata* resembles *P. michiganensis* and the two were often found together; these two species can be distinguished from each other, however, by the characteristic shape and length of their somatic chaetae in segments II–V (Figs. 2a, 3a) and, when present, the shape and position of the genital chaetae (Figs. 2b, 3b). The genital chaetae of *P. michiganensis* are spermathecal but those of *U. uncinata* are penial (length ca. 125 μ). The somatic chaetae in segments II–V in *U. uncinata* measure ca. 115 μ.

Tubificidae

Tubificids are identified by a characteristic shape of the somatic chaetae or their genital chaetae (spermathecal or penial) if present, or by mature male genitalia.

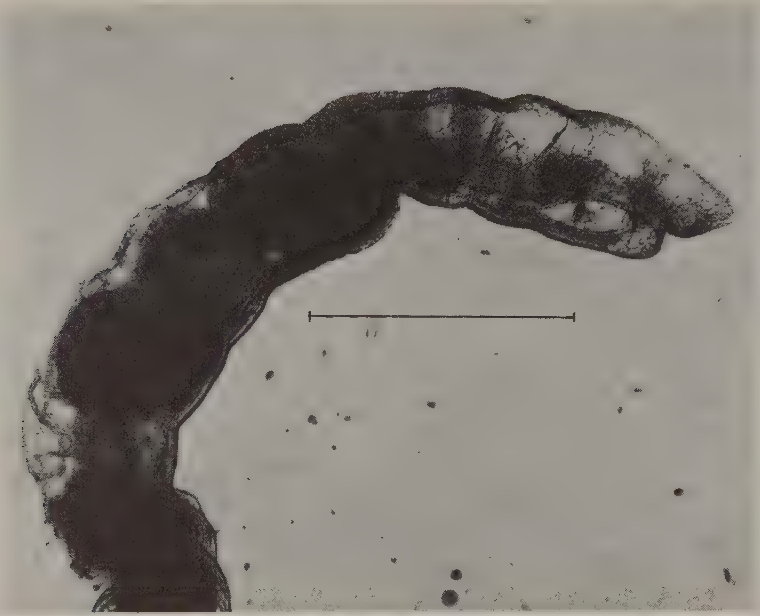


FIG. 26. Anterior half of *Piguetiella michiganensis* (type specimen, slightly compressed and partly cleared). Line equals 600 μ.

Four species of *Aulodrilus* are known from North America: *A. americanus, A. limnobius, A. pigueti,* and *A. pluriseta.* The chaetae permit easy separation of the species. All have bundles of similar bifid chaetae (crotchets), but only *A. pluriseta*[4] and *A. pigueti* have also capilliform or hair-like chaetae (Fig. 7a) in the dorsal bundles. Dorsal crotchets of *A. pluriseta* (Fig. 7) are usually alike on all segments, whereas on *A. pigueti* the outline becomes clavate (Fig. 6b) beginning usually at segment VII. Dorsal chaetae of *A. limnobius* become dorsoventrally compressed and somewhat broadened in segment VII, and the upper (distal) tooth of each dorsal crotchet also becomes reduced (Fig. 5). The chaetae, dorsal and ventral, of *A. americanus* are simple or, at most, minutely notched anterior to about segment VII or VIII, where they begin to change, and at segment X reach a maximum development of a crown (Fig. 4).

Limnodrilus is the largest and perhaps most complex genus of tubificids in the Great Lakes. Seven species have been recognized from the Great Lakes region (Brinkhurst, 1965; Brinkhurst & Cook, 1966); all were found in Lake Michigan in the present study. Mature specimens can be recognized by differences in the shape of the paired penis tubes (Figs. 15–24), but ordinarily *L. udekemianus* can also be identified by the sharply arctuate shape of the chaetae in anterior bundles (Fig. 14).

Reliable identification of *L. hoffmeisteri* can be made only if the individual is mature enough to display a penis tube. Three forms recognized by differences in shape of the penis tubes were considered as variants of *L. hoffmeisteri.* The

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[4] Occasionally specimens of *pluriseta* have multifid dorsal crotchets.

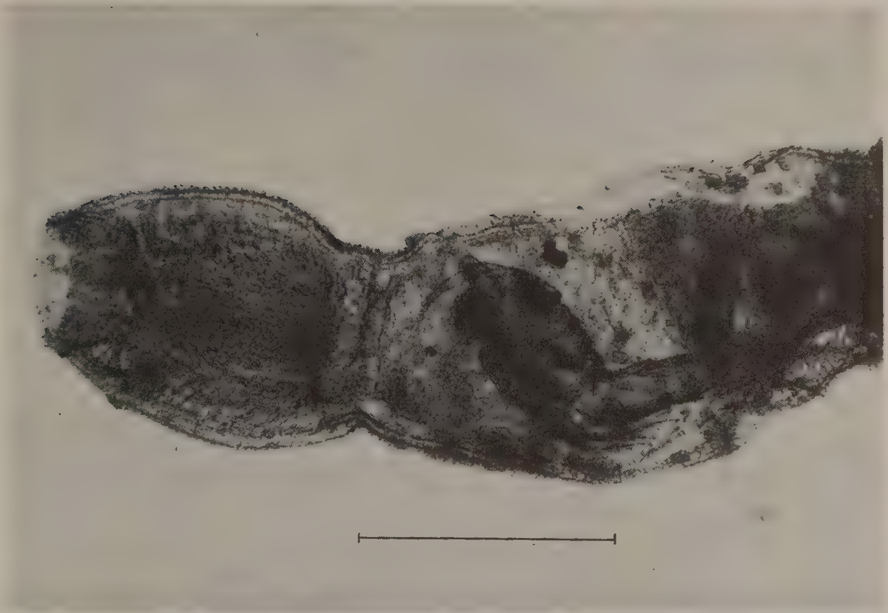

FIG. 27. *Chaetogaster* sp. with ingested harpacticoid copepod (slightly compressed and partly cleared). Line equals 600 μ.

most common (typical) form had a penis tube of the type illustrated in Figure 20. The second had a somewhat larger penis tube, the head of which, although similarly arched and hooded distally, had a toothed or lobate margin (Fig. 19). The third form was intermediate between the typical form and *L. claparedianus*; it had a long, straight penis tube with a flat (poorly hooded) and rounded head (Fig. 21b) that was perpendicular to the long axis of the tube (Fig. 21a). On the crotchets of anterior segments of this form the distal tooth was distinctly longer than the proximal tooth (Fig. 13). On typical *L. hoffmeisteri* the distal tooth of the crotchets was equal to, or slightly shorter than, the proximal tooth (Fig. 12). Each form may warrant separate taxonomic status but until the significance of the differences in the forms is established by further study, I include them as variants of a single species.

Similarly, I recognize two variants of *L. cervix*. Both have penis tubes which are similar except for the shape of the head. The head of the tube is asymmetrically lobate in the typical form (Fig. 24b), but bilaterally symmetrical in the other form (Fig. 23b). The thickness of the translucent outer wall common to both forms is more variable among individuals of the atypical form. In *L. maumeénsis* the size of the penis tube is similar to that of the *L. cervix* forms but the tube never has a translucent outer wall and the tube head is larger and of a distinctly different shape (Fig. 18).

Potamothrix was represented by *P. bavaricus*, *P. hammoniensis*,[5] *P. moldav-*

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[5] This species was not in my collections but R. O. Brinkhurst has identified it in material collected in southern Green Bay by Richard Howmiller and A. M. Beeton (personal communication).

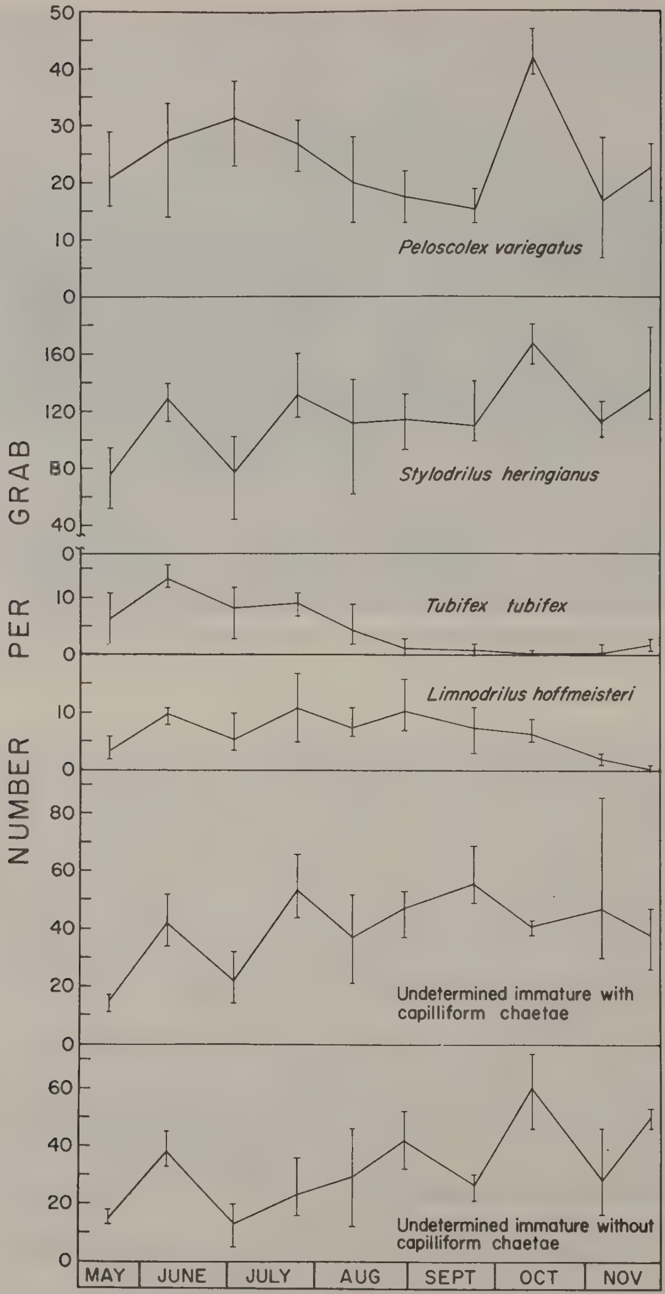

FIG. 28. Average number of selected oligochaetes in samples from Station 31, Lake Michigan, May–November 1960. Vertical lines are ranges.

TABLE I

Stations in southern Lake Michigan at which Naididae were collected, 1960–65[1]
[Data are from samples taken with Petersen, orange-peel, and Smith-McIntyre dredges]

Organism	Density range (no./m²)		
	1–100	101–200	201–400
Amphichaeta sp.	28	—	—
Chaetogaster sp.	28	—	—
Dero digitata	12	—	—
Nais sp.	12, 23	—	7
Ophidonais serpentina	8, 12	—	—
Piguetiella michiganensis	12, 13, 18, 23, 24, 28	17	—
Uncinais uncinata	12, 13, 17, 18, 23, 24, 28	7	—
Vejdovskyella intermedia	24, 28, 29	—	—

[1] See Fig. 1 for location of stations.

iensis, and *P. vejdovskyi. P. bavaricus*, the smallest species of the genus, resembles young *Ilyodrilus templetoni, Peloscolex superiorensis*, and *Tubifex* species, which bear capilliform chaetae. It cannot be distinguished from these unless it is sufficiently mature to have its characteristic spermathecal chaetae (Fig. 11). *P. hammoniensis* can be reliably identified only if it has spermathecal chaetae; otherwise it cannot be differentiated from other species with capilliform chaetae. Sexually mature *P. moldaviensis* can be identified by the spermathecal chaetae (Fig. 10) which are nearly identical to those of *P. hammoniensis*, but the immature forms cannot be reliably separated from other immature tubificids with only bifid chaetae. *P. vejdovskyi* is the most easily distinguished species of this group; individuals of any age can be recognized by the dorsal bundles of crotchets and capilliform chaetae (Fig. 8). Spermathecal chaetae of this species (Fig. 9) also differ slightly from those of others in the genus. Counts of *P. vejdovskyi* in this report include all individuals, regardless of maturity; consequently, the numbers of this species do not give a sound comparison with the abundance of others in the genus.

The species of *Peloscolex, Rhyacodrilus*, and *Tubifex*, and *Ilyodrilus templetoni*, fit the interpretation of Brinkhurst (1965), Brinkhurst & Cook (1966), and Hrabě (1966); additional description is unnecessary.

Ecology

Southern Lake Michigan

Naididae.—Naididae are common in streams, ditches, and shallow water of ponds and lakes. In southern Lake Michigan nearly all naidids were collected at stations 5.5–18.5 m deep (Stations 7, 8, 12, 13, 17, 18, 23, 24, and 28); a few individuals of *Vejdovskyella intermedia* were found as deep as 36.5 m (Station 29).

Accurate measure of the density of naidids was not possible in this study because of the varied methods by which samples were treated. The small size of many of the species caused significant loss when samples were screened and some may have been overlooked when the samples were sorted. A general estimate of the relative abundance of the species of Naididae which occurred in southern Lake Michigan is given in Table I. *Uncinais uncinata* and *Piguetiella michiganensis* were the most common. Others such as *Amphichaeta* sp., *Chaetogaster* sp., and *Nais* sp. may have been more common than suggested by the data of Table I, but may have been overlooked or lost due to their smaller size.

The behavior of most Naididae is unlike that of most other Oligochaeta. Some

TABLE II

Number of common Lumbriculidae, Tubificidae, and total Oligochaeta per square meter from 20 stations at five depths in southern Lake Michigan, September 1962

Location and organism	Depth in meters				
	5.5	18.5	36.5	55	73
Waukegan (Stations 7–11)					
Lumbriculidae					
Stylodrilus heringianus	14	2,817	2,097	1,067	274
Tubificidae					
Limnodrilus hoffmeisteri	[1]—	14	31	—	—
Peloscolex variegatus	—	—	378	—	—
Potamothrix moldaviensis	540	63	—	9	4
P. vejdovskyi	58	18	—	—	—
Tubifex tubifex	—	—	14	—	—
Undetermined immature forms					
With capilliform chaetae	45	203	135	14	—
Without capilliform chaetae	11,970	7,767	270	[1]—	36
Other oligochaetes	418	188	—	—	—
Total	13,045	11,070	2,925	1,090	314
Bottom water temperature in °C	15.5	12.5	5.5	4.5	6.6
Chicago (Stations 12–16)					
Lumbriculidae					
Stylodrilus heringianus	—	3,120	1,966	1,021	68
Tubificidae					
Limnodrilus hoffmeisteri	—	[1]—	50	—	—
Peloscolex variegatus	—	—	95	—	—
Potamothrix moldaviensis	68	58	—	—	—
P. vejdovskyi	[1]—	14	—	—	—
Tubifex tubifex	—	—	4	—	—
Undetermined immature forms					
With capilliform chaetae	22	—	4	—	—
Without capilliform chaetae	1,206	909	405	—	—
Other oligochaetes	63	39	32	—	—
Total	1,359	4,140	2,556	1,021	68
Bottom water temperature in °C	16.5	—	6.0	4.5	6.6
Benton Harbor (Stations 17–21)					
Lumbriculidae					
Stylodrilus heringianus	—	36	3,105	122	301
Tubificidae					
Limnodrilus hoffmeisteri	[1]—	4	198	297	9
Peloscolex variegatus	—	—	—	—	—
Potamothrix moldaviensis	144	9	63	—	—
P. vejdovskyi	4	4	4	4	—
Tubifex tubifex	—	—	[1]—	18	9
Undetermined immature forms					
With capilliform chaetae	9	9	1,310	243	18
Without capilliform chaetae	1,476	792	1,831	211	45
Other oligochaetes	131	78	5	5	—
Total	1,764	932	6,516	900	382
Bottom water temperature in °C	16.5	17.0	9.5	5.0	6.6
South Haven (Stations 23–27)[2]					
Lumbriculidae					
Stylodrilus heringianus	—	[1]—	1,908	4	184
Tubificidae					
Limnodrilus hoffmeisteri	—	—	176	72	58
Peloscolex variegatus	—	—	18	[1]—	—
Potamothrix moldaviensis	4	[1]—	63	—	—

TABLE II (Continued)

Location and organism	Depth in meters				
	5.5	18.5	36.5	55	73
P. vejdovskyi	—	[1]—	[1]—	[1]—	—
Tubifex tubifex	—	—	[1]—	—	—
Undetermined immature forms					
With capilliform chaetae	—	—	495	4	9
Without capilliform chaetae	382	[1]—	689	72	22
Other oligochaetes	87	—	8	14	11
Total	473	2,007	3,357	162	284
Bottom water temperature in °C	16.5	11.0	6.5	4.8	3.5

[1] Species present in grabs by orange-peel and Smith-McIntyre dredges, but data not included here.
[2] Specimens from Station 24 (18.5 m) were lost after initial count.

naidids can swim as well as crawl and others are small enough to be carried by strong water movements. Feeding habits of most species are unknown but some have been observed to feed on detritus and algae (Sperber, 1948). Probably most oligochaetes are herbivorous but some *Chaetogaster* are primarily, or perhaps entirely, predaceous. Hayden (1922) observed that *C. diaphanus* from Douglas Lake, Michigan, "is actively predaceous and even cannibalistic." A specimen of *Chaetogaster*, collected off Saugatuck, Michigan, July 1964, had recently ingested a small harpacticoid copepod (Fig. 27). Visible muscular structure within the body of the copepod rejects the possibility that it was only an exuvial cast.

The period of reproduction of naidids in Lake Michigan is not known, but a peak of sexual activity may occur in late summer and fall. Nearly all *Arcteonais lomondi* at Station 1 in Green Bay during August 1965 were sexually mature. I also collected a number of mature *Stylaria lacustris* in September 1962 at 13.5 m off Racine, Wisconsin (location was not established for this study). In September 1962, mature specimens of *Piguetiella michiganensis* and *Uncinais uncinata* were found at 5.5 m south of Benton Harbor, Michigan (Station 17).

Lumbriculidae and Tubificidae.—Stylodrilus heringianus (Lumbriculidae), and five species of Tubificidae (*Limnodrilus hoffmeisteri, Peloscolex variegatus, Potamothrix moldaviensis, P. vejdovskyi, Tubifex tubifex*) were sufficiently widespread to provide information on abundance and distribution in southern Lake Michigan. Counts of *S. heringianus, Peloscolex variegatus,* and *Potamothrix vejdovskyi* include individuals of all ages and stages of maturity; values for *L. hoffmeisteri, Potamothrix moldaviensis,* and *T. tubifex* include only those which had mature or maturing male genitalia. Tubificids which did not have recognizable genital structure were classified as "undetermined immature" (Table II–V). Immature *L. hoffmeisteri* and *P. moldaviensis* constituted most of the group "undetermined immature forms without capilliform chaetae" and immature *T. tubifex* probably composed most of the "undetermined immature forms with capilliform chaetae."

Where many mature *L. hoffmeisteri* were found but mature *P. moldaviensis* was absent or not abundant (e.g., Station 31), the immature individuals were all or nearly all *L. hoffmeisteri.* Where mature *P. moldaviensis* was common (e.g., Station 7), a significant part of the undetermined immature forms without capilliform chaetae should be attributed to it.

The total number of oligochaetes varied with depth and differed among locations (Table II). A Friedman nonparametric analysis of variance (Siegel, 1956) applied to the ranked density of oligochaetes per grab of a Petersen

TABLE III

Number of common Lumbriculidae, Tubificidae, and total Oligochaeta per square meter at 45.5 m at Station 31 off Grand Haven, Michigan, 1960
[Number of grabs on each date appears in parentheses]

Organism	Date									
	20 May (3)	9 June (3)	2 July (4)	24 July (4)	12 Aug. (4)	30 Aug. (4)	23 Sept. (4)	13 Oct. (3)	6 Nov. (4)	23 Nov. (3)
Lumbriculidae										
Stylodrilus heringianus	1,040	1,773	1,036	1,799	1,519	1,549	1,499	2,259	1,539	1,863
Tubificidae										
Limnodrilus hoffmeisteri	50	135	74	145	101	142	101	85	30	4
Peloscolex variegatus	284	369	425	361	270	236	206	567	233	311
Potamothrix moldaviensis	—	—	—	—	—	—	—	4	—	—
Tubifex tubifex	90	184	111	125	61	17	14	9	7	27
Undetermined immature forms										
With capilliform chaetae	203	576	297	726	503	638	763	554	638	508
Without capilliform chaetae	207	517	179	317	395	567	354	805	375	670
Other oligochaetes	11	5	4	—	16	20	9	14	6	6
Total	1,885	3,559	2,126	3,473	2,865	3,169	2,946	4,297	2,828	3,389
Bottom water temperatures in °C[1]	4.5	4.1	4.5	5.2	4.0	4.9	7.0	4.8	11.5	8.6

[1] Temperature data are from Beeton & Moffett (1964).

dredge from Stations 17–21 and 23–27 revealed that, within the depth limits of these stations, abundance was significantly higher at depths less than 40 m. The nature and availability of food, however, may be a more important criterion of abundance than is depth.

Maximum abundance of *Stylodrilus heringianus* on the east side of the lake was at stations 36.5 to 45.5 m deep (Tables II, III, V). The species was scarce at 45.5 m (the only depth sampled) off Benton Harbor (Station 22, Table IV). On the west side of the lake, *S. heringianus* was most abundant at 18.5 m (Stations 8 and 13). Maximum abundance of *Peloscolex variegatus*, on both sides of the lake was at stations 36.5 m deep, except Station 19 (Tables II and V). This species was also abundant at 45.5 m off Grand Haven (Station 31), but extremely scarce at the same depth off Benton Harbor (Station 22).

Total oligochaetes were conspicuously more abundant at Stations 7 and 8 off Waukegan (Table II), than at other locations. Some source of enrichment may make conditions favorable for tubificids in this area, but the enrichment was not enough to affect adversely *S. heringianus*, a species common throughout the Great Lakes except in excessively enriched or polluted areas. *Potamothrix moldaviensis* and *P. vejdovskyi* were plentiful at Stations 7 and 8. Both species have been collected elsewhere in the Great Lakes (collections in this laboratory) and apparently can sustain some degree of organic enrichment.

Most tubificid species in southern Lake Michigan were widely distributed but not abundant and showed no definite pattern of distribution (Table VI). The poor representation of certain species may result from both natural rarity and loss when the samples were screened.

TABLE IV
Number of common Lumbriculidae, Tubificidae, and total Oligochaeta per square meter at 45.5 m at Station 22 off Benton Harbor, Michigan, 1960
[Number of grabs on each date appears in parentheses]

Organism	Date			
	10 June	21 July	31 Aug.	14 Oct.
	(2)	(4)	(2)	(3)
Lumbriculidae				
Stylodrilus heringianus	47	34	27	243
Tubificidae				
Limnodrilus hoffmeisteri	203	321	216	238
Peloscolex variegatus	—	—	—	4
Potamothrix moldaviensis	47	27	68	108
P. vejdovskyi	47	7	20	27
Tubifex tubifex	14	68	392	14
Undetermined immature forms				
With capilliform chaetae	115	240	297	324
Without capilliform chaetae	493	746	277	1,017
Other oligochaetes	6	224	6	122
Total	972	1,667	1,303	2,097
Bottom water temperature in °C[1]	4.5	4.7	4.3	6.4

[1] Temperature data are from Beeton & Moffett (1964).

Three species of *Aulodrilus* were taken in southern Lake Michigan. The number of *A. pluriseta* was highest but it may be disproportionately large compared to *A. pigueti* which is smaller and was more likely to pass through the screen when the samples were sieved. *A. americanus* is also larger than *A. pigueti* but it was not found in greater numbers. None of these species was present at stations deeper than 18.5 m.

The distribution of *Potamothrix bavaricus* (Table VI) contrasts sharply with that of the other two species of *Potamothrix* (Tables II–V) in southern Lake Michigan: *P. bavaricus* was collected at only one station (Station 22) off Benton Harbor, whereas the other two were widespread and abundant.

Limnodrilus hoffmeisteri was the most abundant and widely distributed member of the genus (Tables II–V); less abundant species were *L. angustipenis, L. claparedianus, L. profundicola,* and *L. udekemianus* (Table VI). *L. angustipenis, L. claparedianus,* and *L. udekemianus* were not found deeper than 36.5 m. *L. profundicola* was eurybathic.

Approximately 40 m appeared to be a critical depth for some species. *Ilyodrilus templetoni, Peloscolex freyi, P. multisetosus,* and *Rhyacodrilus coccineus* were not found beyond this depth. *Peloscolex superiorensis* and *Tubifex kessleri americanus* were found at 36.5 m and deeper.

The density of four common species and the two groups of immature individuals off Grand Haven on ten dates in 1960 (Table III and Fig. 28) showed irregular variation among species and seasons. The causes of the variations are undetermined; the species showed no common trend or inter-relation except for a small peak in June for all but *P. variegatus* and for a common peak in October for *S. heringianus, P. variegatus,* and the "undetermined immature forms without capilliform chaetae" (Fig. 28). The gradual decline of adult *L. hoffmeisteri* and *Tubifex tubifex* in late summer and fall (Table III and Fig. 6) suggests a cessation of sexual activity before fall overturn of the lake. The trend for the group of "undetermined immature forms with capilliform chaetae," which contained mostly *T. tubifex,* suggests that recruitment may be gradual from spring to fall (Fig. 28).

TABLE V

Number of common Lumbriculidae and Tubificidae and total Oligochaeta per square meter on five dates from three stations off Saugatuck, Michigan, 1964
[Three Petersen grabs were made on each date]

Location and organism	Date				
	2 May	23 May	14 June	4 July	25 July
Station 28; 18.5 m					
Lumbriculidae					
Stylodrilus heringianus	112	4	76	49	54
Tubificidae[1]					
Limnodrilus hoffmeisteri	4	9	—	—	9
Potamothrix moldaviensis	—	4	—	—	18
Undetermined immature forms					
With capilliform chaetae	—	—	—	—	9
Without capilliform chaetae	—	—	9	—	14
Other oligochaetes	6	14	23	—	197
Total	122	31	108	49	301
Bottom water temperature in °C	6.6	10.2	8.5	5.5	17.0
Station 29; 36.5 m					
Lumbriculidae					
Stylodrilus heringianus	2,228	2,012	2,250	2,074	2,263
Tubificidae					
Limnodrilus hoffmeisteri	220	297	602	513	495
Peloscolex variegatus	103	63	171	85	90
Potamothrix moldaviensis	—	9	—	31	117
P. vejdovskyi	22	14	27	49	41
Tubifex tubifex	49	36	41	36	36
Undetermined immature forms					
With capilliform chaetae	513	341	473	635	513
Without capilliform chaetae	1,948	949	1,233	1,939	2,007
Other oligochaetes	11	46	23	101	135
Total	5,094	3,767	4,820	5,463	5,697
Bottom water temperature in °C	3.5	5.5	4.0	4.3	5.5
Station 30; 73 m					
Lumbriculidae					
Stylodrilus heringianus	522	346	594	810	579
Tubificidae[2]					
Limnodrilus hoffmeisteri	14	4	18	49	4
Tubifex tubifex	—	—	—	—	8
Undetermined immature forms					
With capilliform chaetae	18	14	31	18	14
Without capilliform chaetae	58	22	36	63	62
Other oligochaetes	—	—	—	5	4
Total	612	386	679	945	671
Bottom water temperature in °C	3.0	4.0	4.0	4.0	4.4

[1] No *Peloscolex variegatus, Potamothrix vejdovskyi*, or *Tubifex tubifex* were collected at Station 28.
[2] No *Peloscolex variegatus, Potamothrix moldaviensis*, or *P. vejdovskyi* were collected at Station 30.

Green Bay

Stations in Green Bay were established in 1965 primarily for other limnological observations; few bottom samples were taken. The data are too limited to permit detailed interpretation but showed considerable differences within the bay among various species, areas, and seasons (Table VII). The use of the Smith-McIntyre dredge in April and a Petersen dredge on later dates may have influenced the counts but the difference in efficiency of the dredges cannot account for all of the great differences between the periods. Station 1, the central part of the Bay, yielded a greater number of species than stations in the southern part. The

TABLE VI

Stations in southern Lake Michigan at which uncommon Tubificidae were collected, 1960–65[1]
[Data are from samples taken with Petersen, orange-peel, and Smith-McIntyre dredges]

Organism	Density range (no./m²)		
	1–50	51–100	101–150
Aulodrilus americanus	7, 8, 12	—	—
A. pigueti	12, 13	—	—
A. pluriseta	7, 18	—	8
Ilyodrilus templetoni	12, 22, 26	—	—
Limnodrilus angustipenis	24	—	—
L. claparedianus	9, 18, 25, 29	—	—
L. profundicola	14, 17, 21, 22, 23, 25, 26, 27, 29, 30, 31	—	—
L. udekemianus	9, 12, 13, 19, 28	18	—
Peloscolex freyi	18	—	—
P. multisetosus	13, 18	8	—
P. superiorensis	20, 28, 29	—	—
Potamothrix bavaricus	—	—	22
Rhyacodrilus coccineus	9, 14, 29	—	—
Tubifex kessleri americanus	20, 22, 25, 31	29	—

[1] See Figure 1 for location of stations.

presence of *S. heringianus* at Station 1 suggests that the environment may be like that in the open lake, and that any adverse effects of inflow from Menominee River are minimal.

Ludington Harbor

One bottom sample was taken near the outfall of the local sewage treatment plant in the harbor of Ludington, Michigan, in October 1965. The sample was obtained to determine species that would be present in an obviously polluted environment (Table VIII). Three species of *Limnodrilus*—*L. cervix, L. hoffmeisteri,* and *L. maumeensis*—and their immature stages constituted nearly 70% of the total oligochaetes. Absence of adults of species similar to *Limnodrilus* justified considering the "undetermined immature forms without capilliform chaetae" as *L. cervix, L. hoffmeisteri,* and *L. maumeensis. L. cervix* and *L. maumeensis* have not been found in the open lake and apparently are restricted to enriched areas. Although *Peloscolex multisetosus* was present in the open lake (Table VI), it also thrives in bays and harbors which receive excessive nutriment.

Environmental Relationships

The present study falls short of adequate coverage of all the various habitats of Lake Michigan; nevertheless, the species composition of oligochaetes gives some clues to the quality of the habitats sampled. Following the saprobic system of Fjerdingstad (1965), species can be placed into three general categories according to quality of the bottom environment: (1) those found only in unpolluted waters (saprophobes); (2) those found in both polluted and unpolluted waters (saprohiles and saproxenes); and (3) those apparently confined to waters enriched by organic matter (saprobionts). In this study, species which were found in clean water include *Stylodrilus heringianus, Peloscolex variegatus,* and *Limnodrilus profundicola. Tubifex kessleri americanus* might also belong to this group, but its restriction to deep water has not exposed it to enrichment in southern Lake Michigan. *L. hoffmeisteri, P. multisetosus, I. templetoni,* and *T. tubifex* are saprophilous. Each was widely distributed and not especially

TABLE VII

Oligochaetes per square meter at Stations 1–6[1], Green Bay, Lake Michigan, 1965
[Data for April are from average of three grabs with Smith-McIntyre dredge, data for May–November are from single grabs with Petersen dredge]

Organism	Date and station											
	28 April			30 May	10 June	16 Aug.		13 Sept.	6 Oct.		5 Nov.	
	2	4	5	3	4	1	4	4	2	4	4	6
Lumbriculidae												
Stylodrilus heringianus	—	—	—	—	—	122	—	—	—	—	—	—
Naididae												
Arcteonais lomondi	70	—	11	—	—	297	14	—	—	—	—	—
Dero digitata	49	5	54	—	—	824	26	—	—	14	—	—
Ophidonais serpentina	—	—	—	—	—	27	—	—	—	—	—	—
Slavina appendiculata	22	5	27	—	—	—	—	—	—	—	—	—
Specaria josinae	—	—	—	—	—	14	—	—	—	—	—	—
Stylaria lacustris	—	—	—	—	—	—	—	—	—	—	—	14
Uncinais uncinata	—	—	—	—	—	14	—	—	—	—	—	—
Vejdovskyella intermedia	16	5	—	—	—	—	—	—	—	—	—	68
Tubificidae												
Aulodrilus americanus	—	—	—	—	—	14	—	—	—	—	—	14
A. limnobius	—	—	5	—	—	—	14	—	—	14	—	—
A. pigueti	—	—	43	—	—	135	14	—	—	14	—	—
A. pluriseta	1,095	405	200	—	—	797	68	26	—	—	—	—
Ilyodrilus templetoni	130	27	86	—	14	216	14	—	—	—	—	—
Limnodrilus cervix	—	—	5	—	—	—	—	—	—	—	—	—
L. claparedianus	—	—	5	—	14	—	—	—	—	—	—	14
L. hoffmeisteri	448	75	49	22	81	446	—	54	14	26	41	27
L. udekemianus	—	—	—	—	—	230	—	—	—	—	—	—
Peloscolex ferox	—	—	5	—	—	—	—	—	—	—	—	14
P. freyi	—	—	—	—	—	270	—	—	—	—	—	54
P. multisetosus	—	102	329	—	—	95	—	14	—	—	14	14
Potamothrix moldaviensis	—	—	—	—	—	14	—	—	—	—	—	—
Rhyacodrilus coccineus	—	—	—	—	—	14	—	—	—	—	—	—
Tubifex ignotus	—	—	—	—	—	837	—	—	—	—	—	—
T. tubifex	481	92	—	14	—	81	—	—	—	—	—	—
Undetermined immature forms												
With capilliform chaetae	4,536	286	275	9	68	608	14	—	297	68	—	14
Without capilliform chaetae	2,932	1,090	1,453	76	176	2,916	81	95	756	473	108	905

[1] Depths of stations were: 1, 5.5 m; 2, 18.5 m; 3, 14.5 m; 4, 12 m; 5, 7.5 m; 6, 7.5 m.

abundant in clean waters, but all were abundant in polluted waters. *L. cervix* and *L. maumeensis* were found only in enriched areas and can be classified as saprobionts.

Further research should permit assignment of other Lake Michigan tubificids to these groups. Most species are probably saproxenes or saprophobes and only a few would thrive in excessive nontoxic organic pollution.

The effect of pollution on the Naididae is poorly understood. A naidid, *Dero*

TABLE VIII

Oligochaetes per square meter from one Petersen dredge grab from the harbor at Ludington, Michigan (Station 32), 20 October 1965
[Depth 9 m; mud bottom]

Organism	Number
Naididae	
Dero digitata	108
Tubificidae	
Aulodrilus pluriseta	41
Ilyodrilus templetoni	41
Limnodrilus cervix	446
L. hoffmeisteri	446
L. maumeensis	27
Peloscolex multisetosus	716
Tubifex tubifex	392
Undetermined immature forms	
With capilliform chaetae	3,746
Without capilliform chaetae	8,775
Total	14,738

digitata, was found not only from Green Bay (Table VII) and from obviously enriched Ludington Harbor (Table VIII) but also from Station 12 off Chicago (Table I), a site where the environment should be free of excessive enrichment. Shrivastava (1962) found *Dero* in water contaminated by industrial effluent. The ability of *Dero digitata* and few other naidids to swim rapidly permits them to seek favorable areas and to avoid intolerable environments; thus the appearance of *D. digitata* in both clean and enriched areas indicates that it is probably a saproxene.

When species of an assemblage are known, changes in proportions of species can be followed with respect to changes in water quality. Should the inshore areas (shallower than 40 m) of Lake Michigan experience gradual organic enrichment similar to that now found in bays and harbors, the species that are now dominant such as *S. heringianus*, *L. profundicola*, and *P. variegatus* would probably disappear, and *P. multisetosus*, *L. hoffmeisteri*, *I. templetoni*, *T. tubifex*, and species of *Potamothrix* would become established and increase in density. Beyond some point the *Potamothrix* would yield to the other four species and to *L. cervix* and *L. maumeensis*, which would spread from the harbors and river mouths where they are now present.

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THE NATURE OF ANTIBODIES AND THE IMMUNE RESPONSE IN RAINBOW TROUT (*SALMO GAIRDNERI*)

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THE JOURNAL OF IMMUNOLOGY
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Vol. 99, No. 3, 1967
Printed in U.S.A.

THE NATURE OF ANTIBODIES AND THE IMMUNE RESPONSE IN RAINBOW TROUT (*SALMO GAIRDNERI*)[1]

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Received for publication March 13, 1967

Despite a surge of interest in comparative immunology in recent years, only a few species of teleost fishes have been tested extensively for immune responses and the mechanisms involved in immunologic reactions produced with their antibodies (1–8). Little is known of the family Salmonidae, which includes salmon, trout, whitefish and grayling, with respect to their immune responses to soluble antigens, the nature of their antibodies and the occurrence and properties of their complement. The purpose of the present study was to examine these aspects of immunology in the single species, the rainbow trout (*Salmo gairdneri*).

MATERIALS AND METHODS

Animals. Large, healthy, adult rainbow trout were used. During the immunization the age of the trout ranged from 2 to 3½ years, the fork length from 27 to 43 cm and the weight from 300 to 1100 g (most of the animals weighed 500 g or more). A few trout were held at ambient water temperatures, which varied from an initial 16°C to a low of 7°C late in the experiments. Most of the fish, however, were maintained at a water temperature near 15°C.

Antigens and immunizations. Three purified soluble antigens were used: crystalline bovine serum albumin (BSA), bovine γ-globulin (BGG) and giant keyhole limpet (*Megathura crenulata*) hemocyanin (KLH).[4] The hemocyanin had been purified by the method described by Campbell *et al.* (9).

Each of 13 trout was given intraperitoneal injections of BSA in saline.[5] Each of 11 other trout was immunized with intraperitoneal doses of BSA in complete Freund's adjuvant (8.5 parts Bayol F to 1.5 parts Arlacel A plus 1 mg of autoclaved *Mycobacterium tuberculosis*/ml).[6] Each of five trout was injected intramuscularly at the base of the dorsal fin with BGG in saline.[7] Nine trout were immunized with KLH in saline: each of four received intramuscular doses,[8] and each of five received intraperitoneal doses.[9] Immunizations with the three antigens also were begun on other trout which died before the series of injections was completed.

Two previously prepared trout hyperimmune isoantisera (10) were used in these studies. Both had saline hemagglutinin titers of 64.

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[1] This research was supported in part by Graduate Research Training Grant CRT 5040 from the National Cancer Institute, United States Public Health Service, Bethesda, Maryland.

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[4] The BSA and BGG preparations were obtained from the Armour Pharmaceutical Co., Chicago, Illinois. The hemocyanin was generously supplied by Dr. Bernard Pollara of the University of Minnesota, Minneapolis, Minnesota.

[5] Each of two fish received 10 mg of BSA in saline on days 0, 10, 21, 73 and 82. One fish received 100 mg of BSA in saline on day 0, 50 mg on day 10, 50 mg on day 21, 10 mg on day 73 and 10 mg on day 82. Each of four fish received 20 mg of BSA in saline on days 0, 9, 20, 30 and 58. Each of six fish received a single injection of 20 mg of BSA in saline.

[6] Each of six fish received 10 mg of BSA in adjuvant on days 0, 17 and 31, and 10 mg of BSA in saline on days 73 and 82. Each of five fish received 10 mg of BSA in adjuvant on days 0, 15 and 30, and 20 mg of BSA in saline on day 58.

[7] Each of five fish received 20 mg of BGG in saline on days 0, 7, 21, 29, 79 and 97.

[8] Each of four fish received 12 mg of KLH in saline intramuscularly on days 0, 18 and 42. One died. The three survivors then received 12 mg of KLH in saline intramuscularly on day 140.

[9] Each of five fish received 20 mg of KLH intraperitoneally on days 0, 10 and 22. Three died. Each of two survivors received 12 mg of KLH intraperitoneally on day 108.

Serologic tests. A single diffusion test similar to the one described by Fahey and McKelvey (11) was used for quantitating circulating foreign soluble antigens in trout serum. In this test 1 part of rabbit anti-BSA, anti-BGG, or anti-KLH precipitating serum was thoroughly mixed with 19 parts of melted agar (12) held at 45°C. Two milliliters of each respective agar-antiserum mixture were pipetted onto clean microscope slides and cooled. Circular wells with diameters of 2.5 mm were punched in the agar, and 0.01 ml of serum to be tested was inserted per well. To provide reference standards, precise quantities of each soluble antigen were diluted in normal rainbow trout serum which did not precipitate with rabbit antisera. After development overnight at 37°C, diameters of precipitate rings around the wells containing test sera were measured in two dimensions, averaged and compared with diameters of precipitate rings of the standards. Limits of sensitivity of the tests were: 25 μg BSA or BGG/ml of trout serum and 50 μg KLH/ml of trout serum.

A micro double-diffusion precipitin test in agar gel (12) was used to detect precipitating antibody.

Two types of passive hemagglutination tests were used: one with tannic acid-treated sheep erythrocytes coated with antigen (13) and the other with formalin-treated sheep erythrocytes coated with antigen (14).

Immunoelectrophoresis tests were performed by the method described by Krauel and Ridgway (15).

Tests for antibody capable of producing passive cutaneous anaphylaxis (PCA) in guinea pigs were made in which trout anti-BSA antisera and rabbit anti-BSA antiserum were used. Twelve guinea pigs weighing from 300 to 500 g were used for the direct PCA test of Ovary (16). Tests for PCA reactions were also made in eight trout weighing 40 to 110 g. Each fish was treated at a separate subcutaneous site with 0.1 ml of: 1) normal trout serum, 2) anti-KLH antiserum from the same trout that provided normal serum, 3) normal rabbit serum, and 4) anti-KLH antiserum from the same rabbit that provided normal serum. After an incubation period of 4 to 5 hr, each fish was injected intracardially with 0.05 ml of KLH (4 mg) and either 0.15 ml of 1% trypan blue in saline or 0.05 ml of 0.5% methylene blue in saline. PCA tests were also attempted with trout anti-BSA sera in two trout weighing 500 g each. The fish were held at 15°C during these tests.

Micro hemagglutination tests were conducted by the method of Chown and Lewis (17).

Tests for hemolysis were performed in small glass Kahn tubes by mixing trout serum, undiluted or diluted in saline, with equal volumes of suspensions of 2 to 5% erythrocytes in either buffered or unbuffered physiologic saline or Tris-HCl buffer (pH 8.0) or barbital buffer specifically designed for use with hemolytic systems which require calcium and magnesium ions (18). Tests were scored for hemolysis either visually or with a colorimeter after 1 to 4 hr at room temperature or after overnight refrigeration.

Procedures for inactivation of complement. Ammonium hydroxide treatment for destruction of C′4 was by the method outlined by Kabat and Mayer (19).

Disodium ethylenediaminetetraacetic acid (EDTA) at a concentration of 0.04 M in phosphate-buffered saline (pH 7.2) or in barbital buffer was used in tests for hemolysis to determine divalent cation requirements.

Gel filtration. Rainbow trout sera were fractionated by the gel filtration method of Flodin and Killander (20). A column of Sephadex G 200 dextran gel (A B Pharmacia) was prepared which had the dimensions 42 by 2.6 cm and a void volume of 42 ml. Concentrations of protein in eluted fractions were determined by ultraviolet light absorption at 280 mμ and by protein analysis with the Beckman/Spinco model 150 ultramicro analytical system which uses the biuret method. Fractions were concentrated by placing them in dialysis bags in 15% weight-to-volume polyvinylpyrrolidone for 6 to 8 hr (21) followed by dialysis against 1% saline overnight in the cold.

Disulfide-bond reduction. Antisera were treated with the disulfide-bond reducing agent, ethanethiol (Eastman Organic Chemicals) (22), and were tested for subsequent loss of antibody activity.

Salt solubility fractionation. Rainbow trout serum proteins were separated on the basis of salt solubility using sodium sulfate at concentrations recommended by Post (23).

Zonal ultracentrifugation. Sucrose density gradient ultracentrifugation was conducted by the method of Kunkel (24) using a Spinco SW 39 swinging bucket rotor at 39,000 r/min in a Spinco model L ultracentrifuge for 18 hr.

Analytical ultracentrifugation. Sedimentation velocities were determined by using a Spinco

TABLE I

Immunologic responses of rainbow trout injected with soluble antigens[a]

Antigen	Test[b]	No. Positive/No. tested	Maximum[c] Titer
BSA[d] in saline	HA	1/13	Not tested
	PPT	2/8	1
BSA in adjuvant	HA	5/11	80
	PPT	1/11	1
BGG[d] in saline	HA	0/5	
	PPT	0/5	
KLH[d] in saline	HA	4/4	80
	PPT	7/7	8

[a] Results are reported only for fish which survived for 2 months or longer after initial injection of antigen. All preimmunization sera were negative except for one which reacted weakly with BSA in precipitin tests.

[b] HA, passive hemagglutination tests with antigen-coated formalinized sheep erythrocytes. PPT, double diffusion precipitin tests in agar gel.

[c] Rabbit antisera developed against these antigens had anti-BSA, anti-BGG or anti-KLH titers of 10^3 to 10^4 in passive hemagglutination tests.

[d] BSA, bovine serum albumin; BGG, bovine γ-globulin; KLH, keyhole limpet hemocyanin.

model E ultracentrifuge at 20°C, a speed of 59,780 r/min, and two cells and phase plate schlieren optics.

Disc electrophoresis. Acrylamide gel electrophoresis tests were run in a model 6 Canalco apparatus following the procedure recommended by the manufacturer.

Anti-trout globulin sera. Rabbit antitrout globulin sera were produced by a method similar to that of Milgrom *et al.* (25), which we have described (26).

RESULTS

Immunologic response to soluble antigens

BSA. Clearance of BSA from the circulation of rainbow trout was variable but generally slow. BSA was detected in sera of some BSA-immunized trout for as long as 138 days after the last injection. Prior injections of BSA increased the clearance rates of subsequently injected BSA. As shown in Table I, 6 of 24 BSA-immunized trout developed hemagglutinins which reacted with BSA. Sera from only three trout injected with BSA had precipitating activity for BSA, and serum from one of the three formed a weak precipitate line in agar with BSA prior to immunization. Anti-BSA agglutinins were first detected on the 31st day and precipitins on the 73rd after initial immunization.

BGG. No precipitating or passive hemagglutinating antibodies for BGG were detected during a 5-month period in sera from rainbow trout immunized with BGG (Table I).

KLH. Six of the seven surviving trout immunized with KLH developed precipitating antibodies by the 42nd to 46th day after initial injection. Later in the course of immunization the single fish which had not reacted earlier also developed precipitins (Table I). Precipitating antibodies to KLH were first detected 22 days after initial injection. Observations which demonstrated that this was a specific immune anti-KLH response included: a) formation of a precipitate in agar with KLH but not with BSA or BGG; b) agglutination of KLH-coated formalinized sheep erythrocytes but not of BSA-coated, BGG-coated or uncoated sheep red cells; c) appearance of the antibodies after specific immunization.

PCA tests with trout antibodies. No PCA reactions were obtained with trout anti-BSA sera or trout anti-KLH sera when tested in either trout or guinea pigs. Also, no PCA reaction was obtained in trout with rabbit antibodies. Control tests in which rabbit anti-BSA antibodies were used in guinea pigs gave strong reactions.

Characteristics of trout antibodies

Immune precipitating antibody. After fractionation of trout antiserum by gel filtration with G 200 Sephadex, immune anti-KLH precipitating antibody was recovered only in the eluate from the first protein peak. This was true of both early antisera (Fig. 1) and late antisera taken 162 days after immunization was begun.

Treatment with ethanethiol (0.047 M) or heating at 59°C for 30 min abolished the specific precipitating activity of the antisera.

Isoimmune hemagglutinating antibody. When rainbow trout isommune sera were examined by gel filtration, isohemagglutinins were found to reside in the first protein peak, or large-molecule fraction, of the eluate. That the recovered agglutinating activity was due to antibodies was shown by the specificity of the reaction which paralleled that of the highly specific unfractionated antisera.

Whereas ethanethiol at a concentration of

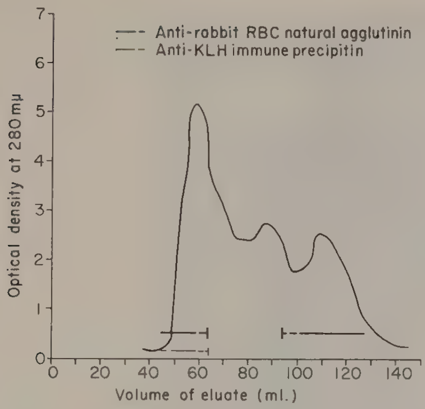

Figure 1. Fractionation of a pool of rainbow trout anti-KLH sera by gel filtration with G 200 Sephadex. (Broken lines represent weak agglutinin and precipitin reactions noted in the respective fractions.)

TABLE II

Effect of 0.047 M ethanethiol (ETSH) on the hemagglutinin titer of normal and immune sera of trout and higher animals

Serum	Hemagglutinin Titer for Rainbow Trout Erythrocytes	Hemagglutinin Titer for Rabbit Erythrocytes
Rainbow trout isoimmune	64	16
Rainbow trout isoimmune plus ETSH	4	0
Normal horse	32	4
Normal horse plus ETSH	4	0
Rabbit hyperimmune anti-rainbow trout erythrocyte	128	
Rabbit hyperimmune anti-rainbow trout erythrocyte plus ETSH	128	

0.047 M markedly decreased hemagglutinating activity of isoimmune trout sera and the trout and rabbit natural hemagglutinins of normal horse serum, it did not reduce the hemagglutinating activity of hyperimmune anti-trout erythrocyte rabbit sera (Table II).

Heating trout isoimmune sera to 59°C for 10 to 15 min reduced its isohemagglutinating activity.

When gel-filtered large-molecule fractions of rainbow trout isoimmune sera were subjected to sucrose density gradient ultracentrifugation, their isohemagglutinating activity was found only in a zone immediately below the middle of the gradient (Fig. 2).

Antibody-containing fractions of eluate from the ascending portions of the first peak from gel filtration of trout isoimmune sera were pooled and examined by analytical ultracentrifugation. Separate examinations made of two trout isoimmune sera gave similar results. Two peaks (Fig. 3, lower) developed in each pool; sedimentation coefficients were 13.9 S and 13.2 S for the fast peak and 10.7 S and 10.5 S for the slow peak.

The immunoelectrophoretic mobility of the isoimmune antibodies was similar to that of beta globulins in human serum (Fig. 4). This similarity was determined by using both rabbit anti-rainbow trout globulin and rabbit anti-rainbow trout whole serum reagents. Fractions of trout antisera containing clearly detectable isoimmune hemagglutinins invariably developed a β-globulin arc in the immunoelectrophoresis tests. This was true for isohemagglutinin-containing fractions of trout antisera whether separated by gel filtration (Fig. 5), by sucrose density gradient ultracentrifugation or by sodium sulfate fractionation (Fig. 6). Conversely, fractions from the above separations which lacked isohemagglutinating activity commonly were without a demonstrable β arc.

Three principal protein bands with the same mobility as the slowest bands in unfractionated antiserum formed upon electrophoresis of an antibody-containing fraction from the first peak of gel-filtered isoimmune trout serum (Fig. 7). The broad band in the large-molecule fraction which migrated most rapidly was identified as a lipoprotein associated with maturity in the female. Therefore, immune antibodies are contained in the slower-migrating bands resolved by this procedure.

Natural hemagglutinins in rainbow trout sera. Natural hemagglutinins for rabbit erythrocytes, mouse erythrocytes and human erythrocytes are present in trout sera. Absorption tests demonstrated that these hemagglutinins are specific. Titers for rabbit red cells ranged as high as 64.

Gel filtrations of four rainbow trout sera (two immune, one pooled immune and one pooled normal) each resulted in recovery of natural agglutinins for rabbit erythrocytes from both large-molecule and small-molecule fractions of the

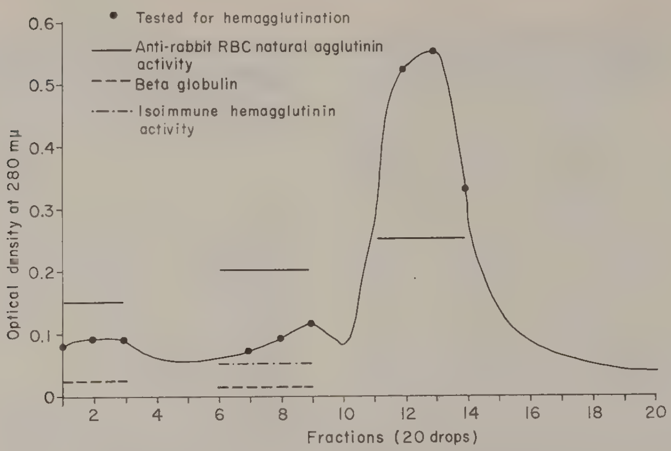

Figure 2. Zonal ultracentrifugation in a 10 to 40% sucrose density gradient of pooled fractions from the ascending portion of the first peak from G 200 Sephadex gel filtration of rainbow trout isoimmune serum. Fractions tested for hemagglutinins were also tested for β-globulin by specific anti-trout globulin rabbit serum. Fraction 1 came from the bottom and fraction 20 from the top of the gradient.

eluates (Fig. 1). Natural agglutinin titers of 8 were obtained in large-molecule fractions of one trout isoimmune serum and of 4 in small-molecule fractions of the same serum.

A series of sodium sulfate fractionations of trout isoimmune sera resulted in complete separation of natural (anti-rabbit erythrocyte) and immune (anti-trout erythrocyte) antibody activity (Table III). When the fraction containing only natural agglutinin activity was further separated by gel filtration, natural agglutinins were again recovered in fractions representing two molecular sizes. Immunodiffusion tests demonstrated that fractions containing large-molecule and small-molecule natural antibodies contained at least one antigenically-related component.

As shown in Figure 7, a protein band was detected in the small-molecule fraction obtained by gel filtration of rainbow trout serum which had mobility similar to that of slower-migrating bands in the large-molecule fraction. This may represent a lack of complete separation of small molecules from large molecules. It is unlikely, however, that natural hemagglutinin activity detected in the small-molecule fraction was due to contamination by large molecules, because: 1) no immune isohemagglutinin activity was ever detected in small-molecule fractions and 2) certain intermediate fractions of the eluate were invariably without natural hemagglutinin activity (see Fig. 1).

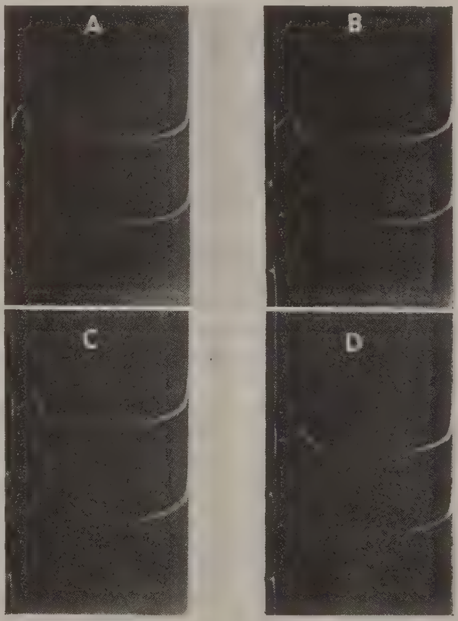

Figure 3. Sedimentation velocity experiment on a small-molecule fraction of rainbow trout serum containing natural hemagglutinins (*upper*) and a large-molecule fraction containing isoimmune and natural hemagglutinins (*lower*). *a*) 0 min; *b*) 8 min; *c*) 16 min; and *d*) 24 min. (Protein concentrations: 1.35 mg/ml (*upper*); 2.45 mg/ml (*lower*). Solvent: Tris-HCl buffer 0.1 M, pH 8, 0.2 M NaCl.)

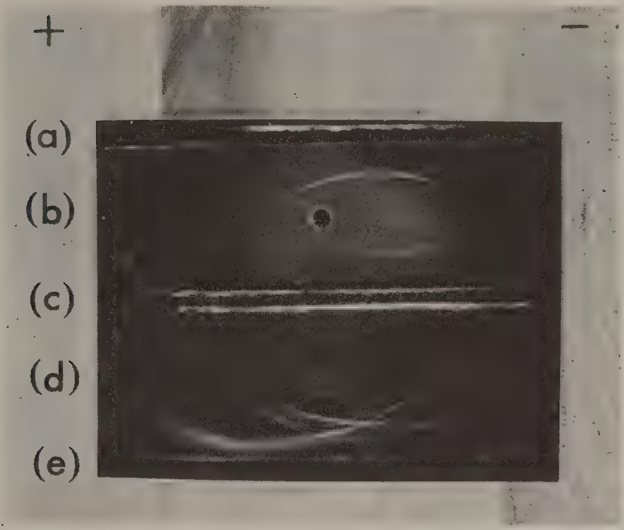

Figure 4. Immunoelectrophoretic comparison of rainbow trout serum globulins with human serum. *a*) Rabbit anti-sockeye salmon (*Oncorhynchus nerka*) hemolysate antiserum; *b*) normal rainbow trout serum; *c*) rabbit anti-rainbow trout globulin antiserum; *d*) human serum; and *e*) rabbit anti-human serum antiserum.

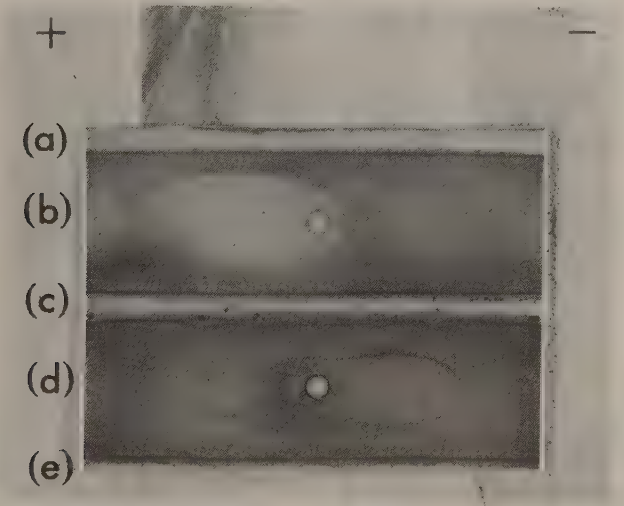

Figure 5. Immunoelectrophoretic comparison of small-molecule (natural-antibody-containing) and large-molecule (natural- and isoimmune-antibody-containing) fractions from gel-filtered rainbow trout isoimmune serum. *a*) Rabbit anti-rainbow trout serum antiserum; *b*) small-molecule fraction; *c*) rabbit anti-rainbow trout globulin antiserum; *d*) large-molecule fraction; and *e*) rabbit anti-rainbow trout serum antiserum. (Slide was stained for protein with amidoschwarz.)

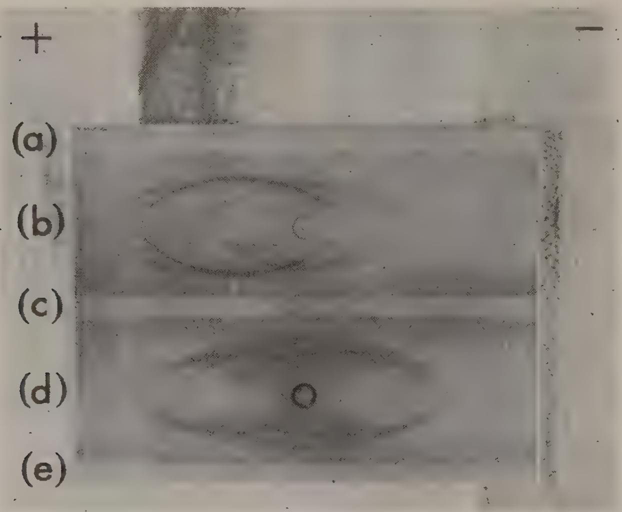

Figure 6. Immunoelectrophoretic comparison of the fraction of rainbow isoimmune serum obtained by sodium sulfate separation which contained only natural antibody activity with the fraction which contained only isoimmune antibody activity. *a*) Rabbit anti-rainbow trout serum antiserum; *b*) natural-antibody-containing fraction; *c*) rabbit anti-rainbow trout serum antiserum; *d*) isoimmune-antibody-containing fraction; and *e*) rabbit anti-rainbow trout serum antiserum. (Slide was stained for protein with amidoschwarz.)

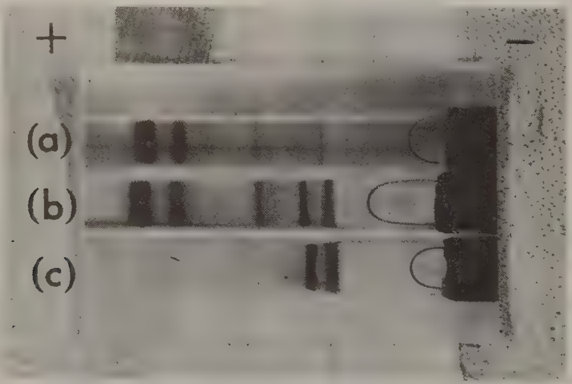

Figure 7. Disc electrophoresis of unfractionated rainbow trout isoimmune serum, a fraction of the serum containing large molecules (with isoimmune and natural antibodies), and a fraction of the serum containing smaller molecules (with only natural antibodies). These fractions were obtained by gel filtration of the serum. *a*) Small-molecule fraction; *b*) rainbow trout whole antiserum; and *c*) large-molecule fraction. (Gels were stained for protein with amidoschwarz.)

Ethanethiol very effectively reduced the activity of the natural agglutinins (Table II).

Heating trout sera to 58°C for 15 to 30 min usually abolished their natural agglutinating activity for rabbit red blood cells, although heating at 50°C or 56°C did not.

After sucrose gradient ultracentrifugation of large-molecule fractions of rainbow trout serum prepared by prior gel filtration, natural anti-rabbit RBC agglutinins were found in all three protein peaks in the gradient (Fig. 2).

The small-molecule natural anti-rabbit RBC agglutinin had a sedimentation coefficient of 4.2 S (Fig. 3, upper). The large-molecule natural anti-

TABLE III

Location of hemagglutinating activities in rainbow trout isoimmune serum fractions obtained by treatment with sodium sulfate

Serum Fraction	Hemagglutinin Titer	
	Isoimmune hemagglutinin	Natural rabbit RBC agglutinin
Precipitate from addition of 17% sodium sulfate	4	1
Supernatant fluid after precipitation by 17% and 22% sodium sulfate	0	4
Precipitate obtained from 17% sodium sulfate supernatant fluid after increasing the concentration of sodium sulfate to 22%	2	0

rabbit RBC agglutinin was contained in the same gel filtration fractions of trout serum which contained isoimmune hemagglutinins. As previously stated, these fractions developed two peaks during ultracentrifugation (Fig. 3, lower) with sedimentation coefficients of about 13.5 S and 10.5 S.

Immunoelectrophoretic tests on rainbow trout sera and serum fractions containing natural agglutinin activity (fractions obtained by zonal ultracentrifugation, salt solubility separation and gel filtration) did not clearly reveal single precipitin arcs representing the natural agglutinins. However, in some fractions of trout sera with natural anti-rabbit erythrocyte agglutinating activity but without immune anti-trout RBC agglutinins, the only detectable components resembled albumins and alpha globulins (Figs. 5 and 6).

Characteristics of natural hemolytic activity of rainbow trout sera. In rainbow trout sera, natural hemolytic activity was present against erythrocytes of all of the 18 species of mammals, birds, amphibia and fishes tested except rainbow trout and salmon (genus *Oncorhynchus*). Absorption of pooled trout sera with formalinized erythrocytes of either sheep or rabbits removed all hemolytic activity for fresh red blood cells of both species. Sera from several nonsalmonid fish species were also tested for hemolytic activity against the erythrocytes of various species, including mammals. They were frequently less hemolytic than rainbow trout sera and possessed different patterns of hemolytic specificities.

Ammonium hydroxide treatment to destroy C′4 did not significantly reduce hemolytic activity of rainbow trout serum for rabbit erythrocytes. Similar treatment of a control rabbit serum containing anti-trout erythrocyte antibody and rabbit complement reduced the hemolytic activity of this serum for trout erythrocytes.

Heat-inactivated rainbow trout serum did not regain its hemolytic activity when combined with guinea pig complement, with hemolytically active fish sera of different hemolytic specificities than trout sera, with nonhemolytic fractions of pooled trout sera derived by gel filtration, or with C′4-depleted rabbit serum. Also, the addition of heterologous or homologous antibody or complement did not increase the natural hemolytic activity of trout serum for rabbit RBC's, although heterologous antibody has been shown to increase natural hemolytic titers of amphibian and elasmobranch sera (27, 28). Thus, neither horse natural antibody, heat-inactivated rainbow trout serum, guinea pig complement nor heat-inactivated English sole (*Parophrys vetulus*) serum (which also contains natural hemolysins for rabbit erythrocytes) increased the hemolytic activity of fresh trout serum for rabbit erythrocytes.

Other characteristics of the natural hemolytic activity of rainbow trout sera were: a) hemolytic activity was recovered exclusively in the first peak of protein obtained by gel filtration (Fig. 8); b) fractionation of serum by sodium sulfate destroyed all hemolytic activity; c) ethanethiol treatment destroyed hemolytic activity; d) 0.04 M EDTA blocked hemolytic activity; and e) at least one component involved in natural hemolytic activity is extremely heat labile, being inactivated at about 42°C.

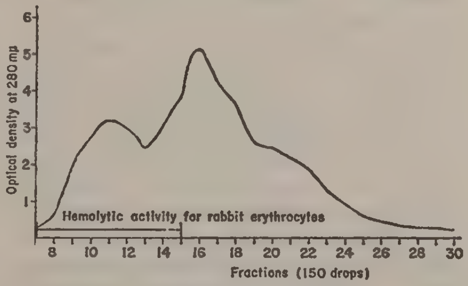

Figure 8. Fractionation of pooled sera of normal rainbow trout by gel filtration with G 200 Sephadex (broken line represents weak reaction).

DISCUSSION

The present studies demonstrate that although BSA and BGG are poor antigens for rainbow trout, KLH is an excellent antigen.

Fractionation of rainbow trout antisera developed against either erythrocytes or soluble antigens revealed that the immune antibody was always of large-molecular size. This is in contrast to the production of antibody in the higher animal species and in the lemon shark (*Negaprion brevirostris*) (3) and the goldfish (*Carassius auratus*) (8) in which a heavy-to-light antibody shift occurs during prolonged immunization with viral antigens. It has been reported by Sigel and Clem (3), however, that gar (*Lepisosteus platyrhincus*) anti-viral antibodies and margate (*Haemulon album*) anti-viral and anti-BSA antibodies are found only as heavy molecules even after prolonged immunization. Pollara *et al.* (29) found the anti-brucella antibodies produced by the guitarfish (*Rhinobatos productus*), horned shark (*Heterodontus francisci*), paddlefish (*Polyodon spathula*), gar, bowfin (*Amia calva*) and carp (*Cyprinus carpio*) are also heavy molecules. Therefore, some elasmobranchs and some teleosts appear to produce a light antibody molecule after prolonged immunization and some do not. This difference may be a function of the antigen used.

In this study we found that the isoimmune hemagglutinating and the immune precipitating antibodies in rainbow trout sera were always of large-molecular size, whereas the natural hemagglutinins were of two molecular sizes. Trout serum contains natural hemagglutinins that clearly belong to a different molecular species than immune hemagglutinins, since they are separable from immune hemagglutinins by gel filtration, salt solubility fractionation and zonal ultracentrifugation.

The natural hemagglutinating antibodies of rainbow trout may have a polymer-monomer relationship similar to that of the immune hemagglutinating antibodies in the lemon shark (30). In this shark the 19 S immunologically-active antibody was postulated by Clem and Small to be a pentamer of the immunologically active 7.5 S antibody. Marchalonis and Edelman (31) also found this same polymer-monomer state of antigenically identical globulins in another elasmobranch, the smooth dogfish (*Mustelis canis*), but only the polymer had immune antibody activity. We are unaware of any reports of a polymer-monomer relationship for natural antibodies in any species. Recently a 3.5 S immune antibody in rabbit serum was isolated (32), which on the basis of antigenic specificity was thought to be composed of native or slightly modified H-chains. This antibody was incomplete or univalent and may be a degradation product or the result of incomplete or improper synthesis.

The sedimentation coefficients of 13.2 to 13.9 S and 10.5 to 10.7 S which we found for rainbow trout serum fractions containing large-molecule (natural) and isoimmune agglutinins and of 4.2 S for the small-molecule (natural) agglutinins are similar to the sedimentation coefficients reported for proteins in sera from other teleost fishes. Roberts and Seal (33) published uncorrected sedimentation coefficient values for ultracentrifugally resolvable peaks of whole sera from a variety of animal species. Although they used a different diluent and higher protein concentrations than we used, their results with sera of carp and catfish (*Ictalurus punctata*) and our results with trout sera are similar. The sera of all three species contained fast-sedimenting components of 13.2 to 13.9 S. In contrast, they found that rabbit sera have a fast component of 16.7 S and human sera have a fast component of 15 S.

The natural hemolytic system of rainbow trout serum is similar in some ways to complement-antibody hemolytic systems in the sera of mammals, amphibia and other fishes (27, 28, 34–36). All are similar with respect to heat lability, inhibition by EDTA and specificity. The natural hemolytic activity of trout serum, however, differed from complement-antibody hemolytic activity in other animals, in that heat-inactivated trout sera could not be reactivated by the addition of various complements and sera, that heterologous or homologous antibody or guinea pig complement did not increase hemolytic titers and that ammonium hydroxide treatment to destroy C′4 did not significantly affect the hemolytic activity of trout serum.

SUMMARY

Rainbow trout were immunized with three purified soluble proteins of different molecular sizes: BSA, BGG and KLH. Passive hemagglutinating antibodies were detected in a few of

the trout anti-BSA sera on the 31st day and precipitins on the 73rd day after the initial injection of antigen. Only a small number of BSA-injected trout developed detectable antibodies at any interval. No detectable antibodies to BGG were produced by rainbow trout during a 5-month period of immunization. Specific anti-KLH precipitating antibodies were detected by the 22nd day after initial injection of antigen and were eventually produced by all surviving KLH-injected trout.

Rainbow trout isoimmune hemagglutinating antibodies resided in a serum fraction which contained 10.5 S and 13.5 S components. They migrated as β-globulins in immunoelectrophoresis.

No large- to small-molecule production shift analogous to the 19 S to 7 S production-shift in mammals was observed with either rainbow trout isoimmune hemagglutinating or immune precipitating antibody.

Specific natural anti-rabbit RBC hemagglutinins of rainbow trout sera consisted of both large and small molecules. These natural hemagglutinins represent distinctly different molecular species than immune isohemagglutinins.

The natural hemolytic activity of rainbow trout serum was in some respects similar to that of the antibody-complement systems of other species. However, it differed in that heat-inactivated trout sera could not be reactivated by various complements and sera, that heterologous or homologous antibody or guinea pig complement did not increase serum titers and that ammonium hydroxide did not significantly affect hemolysis by trout serum.

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Use of Fish Brain Acetylcholinesterase to Monitor Pollution by Organophosphorus Pesticides

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U. S. Bureau of Commercial Fisheries Biological Laboratory
Gulf Breeze, Florida[2]

The organophosphorus pesticides are toxic because they inhibit the enzyme acetylcholinesterase (AChE), which is essential to nerve conduction. Weiss (1,2,3) reported that very low concentrations of these pollutants could be detected by measuring the degree of inhibition of this enzyme in brains of exposed fish. He suggested that this technique be used to monitor pollution in natural waters (4,5). Recovery to normal

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[2] Contribution No. 74

Bulletin of Environmental Contamination & Toxicology,
Vol. 2, No. 3, 1967, published by Springer-Verlag New York Inc.

AChE levels after exposure to organophosphorus pesticides may take a month or more (3); it may be possible therefore to detect not only present but past pollution. The purpose of this study was to investigate the feasibility of using this technique to monitor organophosphorus pesticide pollution in estuarine waters.

Materials and Methods

This study was conducted at the Bureau of Commercial Fisheries Biological Laboratory, Gulf Breeze, Florida, between October 1965 and November 1966. Species selected were spot (Leiostomus xanthurus) and sheepshead minnows (Cyprinodon variegatus). Both species occur from Texas to New England and are generally abundant and easily obtained. Seven laboratories along the Atlantic and Gulf Coasts cooperated in this study by sending us fish from their areas periodically (about every 2 months) for AChE assay. Fish were frozen as soon as possible after capture and shipped in dry ice; we previously determined that enzyme activity is not affected by this treatment.

To determine AChE activity, we removed the brain from a fish and weighed it on a tared piece of aluminum foil. The brain was then homogenized in 4 ml of a phosphate buffer (pH 7.2) of the following composition: 16.72 g $Na_2HPO_4 \cdot 12H_2O$ and 2.72 g KH_2PO_4 dissolved in 1 liter of distilled water. We diluted a 2-ml aliquot of the homogenate with sufficient buffer to make the tissue concentration 3.5 mg of tissue per ml of buffer. This material was incubated 4 hours at 25°C. We then added 1 ml of the diluted homogenate to 1 ml of 0.004 M solution of acetylcholine iodide and allowed the reaction to proceed 20 minutes at 25°C. We determined the residual acetylcholine colorimetrically at 525 mμ by the method of Hestrin (6) and calculated the level of activity on the basis of micromoles of substrate hydrolyzed per hour per mg of brain tissue. Since previous studies at this laboratory and by others (2) showed a decrease in activity per unit weight as fish-brain weight increases, we calculated a line of best fit for each species using data from 155 spot and 168 sheepshead minnows. This line was considered to represent 100% activity. In both species, the results of more than 80% of the analyses were between 90 and 110%; we consider these limits to represent normal variation. Groups that averaged less than 90% AChE activity were considered to have experienced significant exposure to some anti-cholinesterase agent.

Evidence of Pollution

We conducted AChE assays on 93 samples of spot and sheepshead minnows from 43 stations during this study; sample size ranged from 2 to 29 fish, and 1084 individual assays were performed. We found low enzyme activity in 17 samples (18.3%), but 13 of these were from only two areas (Table 1). The fish that showed low AChE activity (73% to 88% of normal) from South Carolina came from the vicinity of the Ashley River near Charleston. This river receives wastes from plants producing a variety of organophosphorus compounds. Williams and Sova (8) reported that Atlantic menhaden (*Brevoortia tyrannus*) and Atlantic croakers (*Micropogon undulatus*) from this river also exhibit low enzyme activity. Fish from the Galveston area with low activity (75% to 84% of normal), generally came from stations along the eastern edge of Trinity Bay. Samples from four other stations assayed as low as 77% to 85% of normal, but depression of enzyme activity in fish from these areas was not consistently present.

TABLE 1

Summary of Data on Organophosphorus Pesticide Monitoring October 1965 - November 1966

Biological Laboratory	Fish Species[1]	Number Assayed	Number of Stations	Number of Samples	Number Positive[2]
Chesapeake Biological Laboratory, Solomons, Maryland	S	20	1	1	0
Gulf Coast Research Laboratory, Ocean Springs, Mississippi	S	35	3	4	1
	M	43	1	4	1
Bears Bluff Laboratories, Wadmalaw Island, South Carolina	S	111	8	9	4
	M	97	4	6	0
Virginia Institute of Marine Science, Gloucester Point, Virginia	S	25	1	2	0
	M	55	1	4	0
Bureau of Commercial Fisheries Biological Laboratories:					
Gulf Breeze, Florida	S	104	4	12	0
	M	194	1	15	0
St. Petersburg Beach, Florida	S	97	2	8	1
	M	57	2	4	0
Beaufort, North Carolina	S	39	1	3	1
Galveston, Texas	S	181	12	19	8
	M	26	2	2	1
		1084	43	93	17

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[1] S = spot, *Leiostomus xanthurus*; M = sheepshead minnow, *Cyprinodon variegatus*.

[2] Less than 90% of normal AChE activity, presumably indicating pollution.

Potential Value of the Technique

This study indicates that organophosphorus pesticide pollution in estuaries along the Atlantic and Gulf coasts is not yet widespread, but should be followed, preferably by a technique that is dependable and not too costly. The techniques used by us are relatively straightforward and could readily be employed by other laboratories at moderate expense. The chief difficulty lies in the mechanics of handling and shipping the frozen samples.

We suggest several modifications of our procedures which would decrease the time required for AChE determinations without detracting from the value of the data. The 4-hour incubation period following homogenization of the brain tissue can be eliminated; a trained operator could then complete approximately 25 samples per day. Instead of analyzing individual fish, brains of 5 to 10 fish of uniform size from a station can be analyzed as a composite sample and yield a statistically valid datum. Additional fish species are presumably suitable for use as monitors; we are currently evaluating several species of the genus *Fundulus* for this purpose.

Use of these techniques for the periodic surveillance of estuarine fish populations will enable the biologist to recognize incipient and chronic low levels of organophosphorus pollution in estuaries. Armed with such data, we can initiate remedial action before an environment is permanently destroyed.

Acknowledgments

We acknowledge the technical assistance of Donald C. Speed. We thank Dr. Robert F. Johnson for reviewing the manuscript.

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Reprinted from Transactions of the American Fisheries Society
Vol. 96, No. 2, 21 April 1967
pp. 151–156

Marking Post-larval Paralichthid Flounders with Radioactive Elements[1]

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ABSTRACT

The problem of marking post-larval flounder (*Paralichthys* spp.) with radioisotopes was approached in two ways: (1) by marking with radioactive cerium and cobalt, and (2) by increasing the concentration of stable cobalt in the fish and then making it radioactive through exposure to neutrons in a nuclear reactor (activation analysis).

In the first approach, both cerium 144 and cobalt 60, introduced into the food or water, were used satisfactorily as marks for post-larval flounder. The radioactivity obtained from the water was retained longer than that obtained from food. The amount of cerium accumulated by the fish in 24 hours did not increase when the concentration of cerium 144 was raised from 0.4 to 1.0 μc/ml of sea water, but the amount of cobalt 60 accumulated increased when the concentration was raised from 0.01 to 1.0 μc/ml of sea water.

In the second approach, fish were marked by holding them for 24 hours in sea water with different concentrations of stable cobalt. Fish held 24 hours in sea water containing 15.62 μg of stable cobalt per ml of sea water and then held for 36 days in flowing sea water contained enough stable cobalt to be identified in the laboratory by activation analysis.

INTRODUCTION

The best method of gathering information concerning certain species of fish is to mark, release, and recapture a portion of the population. Techniques such as attaching tags or clipping fins are commonly used for marking large fish, but are unsuitable for small post-larvae. Larval fish have been marked by injection of biological stains or dyes intramuscularly (Dunn and Coker, 1951) and subcutaneously (Wigley, 1952). Injection, however, requires handling of individual fish which may result in injury. In addition, the obvious discoloration of an injected or dyed fish may make it more susceptible to predators.

The recent development of radioisotope techniques has given fishery biologists a new method of marking larval fish which eliminates many of the disadvantages of the methods mentioned above. Scott (1961) found that injections of either iron 59 or iron 55 could be used as a mark for fish over 8 cm long. To mark smaller fish, a method of introducing the radioisotope through food was required, since iron will not stay in solution in water and injection would harm the fish. The use of radioactive cesium 137 as a mark was tested in lamprey ammocoetes and other fish (Scott, 1962). The 47-day effective half-life which was calculated indicated that cesium 137 could be used for short periods. Russian scientists (Kirpichnikov, Svetovidov, and Troshin, 1958; Bogoiavlenskaia and Karzinkin, 1958; Shekhanova, 1958; Bogoiavlenskaia, 1959; Karzinkin, Soldatova, and Shekhanova, 1959) established that calcium 45 can be detected in fish from 1½ to 2 years after marking, but that phosphorus 32 remains useful as a mark for only 2½ to 3 months. The disadvantage of calcium 45 and phosphorus 32 is that both emit beta radiation, which is more difficult to detect than gamma radiation.

This paper describes two methods for marking post-larval flounder (*Paralichthys* spp.): (1) marking with ratioactive cerium and cobalt, and (2) marking with stable cobalt which was subsequently detected by activation analysis.

MATERIALS AND METHODS

Three species of flounder, *Paralichthys dentatus*, *P. albigutta*, and *P. lethostigma*, were collected with a 1-mm-mesh net, one meter in diameter as they migrated into the Newport River estuary near Beaufort, North Carolina. The species were not separated in the experiments.

The radioisotopes used were obtained from

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[1] This research was supported through a cooperative agreement between the U. S. Fish and Wildlife Service and the U. S. Atomic Energy Commission.

[2] Based on part of a Master's thesis submitted to North Carolina State University, Raleigh, North Carolina.

TABLE 1.—*Summary of cerium 144 experiments*

Experiment number	Number of fish marked	Average weight (mg)	Method of marking	Concentration of isotope in water ($\mu c/ml$)	Marking time (hours)	Days in flowing sea water	Mean cpm/fish at end of experiment
1	6	26	Water	0.002	24	1	0
2	10	41	Water	0.400	24	33	344
3	15	85	Water	1.000	24	50	110
4	10	49	Food	0.400	24	32	68

the Oak Ridge National Laboratory, Oak Ridge, Tennessee, and were diluted to obtain the desired concentration of radioactivity. Specific concentrations are given with the description of each experiment. The stable cobalt was cobalt (ous) chloride ($CoCl_2 \cdot 6H_2O$).

Three detection systems were used to radioassay the flounder: (1) an underwater Beta-Gamma monitor and a 3-inch-diameter crystal with a low-noise multiplier phototube (a portable system that could be used in a field experiment); (2) a decade scaler and a scintillation well counter, set up in the laboratory as a reserve for the portable detector; and (3) a 512-channel analyzer with a 4- by 4-inch NaI (Tl) crystal mounted on a 3-inch phototube and a large shield (inside dimensions 2 × 2 × 3 feet), for identification of activation products.

Both food and water were used to introduce the mark into the fish. Food organisms were held for a fixed period of time in water containing the desired concentration of isotope, rinsed in nonactive water, and fed to the fish. Fish were allowed to feed for either 24 or 48 hours, then removed and placed in flowing water. Fish also were marked by placing them in water containing a predetermined amount of the element, and leaving them for either 24 or 48 hours to accumulate the element; they were then rinsed in nonactive sea water and placed in glass vials containing 5 ml of sea water for radioassay. Fish were assayed individually for 3 min or until 10,000 counts were obtained, whichever occurred first. The size of the vial restricted the flounder's movements so that the counting geometry was constant. Next, the fish were removed from the glass vial and placed in a bag made of fine-mesh net. After excess water was blotted off the fish were weighed to the nearest milligram. After weighing, the fish were removed and the tare weight of the net bag was obtained.

The effective half-life of the isotope in the experimental fish was calculated from the formula

$$T_e = \frac{\log 2}{b},$$

where T_e is the effective half-life and b is the the slope of the calculated regression line of the slower component of the retention curve. Then the relationship between effective half-life and physical half-life is

$$\frac{1}{T_e} = \frac{1}{T_p} + \frac{1}{T_B},$$

where T_p is the physical half-life and T_B is the biological half-life.

MARKING WITH RADIOISOTOPES

Three concentrations of cerium 144 in sea water (0.002, 0.4, and 1.0 $\mu c/ml$ of sea water) were used to determine the amount of the isotope necessary to mark the fish. After exposure to 0.002 μc of cerium 144 (Experiment 1, Table 1) only three of the six fish tested contained a measurable amount of radioactive cerium, and after 24 hours in nonactive water no measurable activity remained. All fish marked in water containing 0.4 μc cerium (Experiment 2) contained a measurable amount of cerium 144 when removed from radioactive sea water, and could be distinguished from unmarked fish after 33 days in flowing sea water. The fish marked in water containing 1.0 μc of cerium per ml of sea water (Experiment 3) contained a statistically significant (*t*-test) mean activity relative to control fish after 50 days in flowing sea water. The rate of loss of cerium 144 (Experiment 3) was rapid during the first 10 days after removal from the active water, then remained constant during the next 40 days (Figure 1). Thus, the retention curve may be separated into two components. The slope of the regression line of the slower

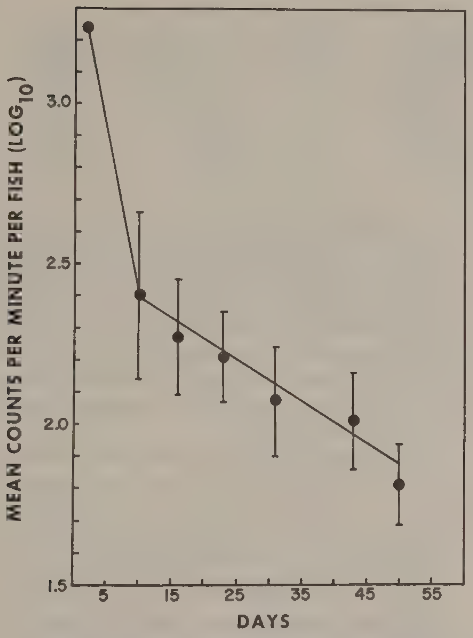

FIGURE 1.—Cerium 144 remaining in flounder held in flowing sea water, after they had been marked in sea water containing 1.0 μc cerium 144 per ml (Experiment 3, Table 1). Vertical lines are one standard deviation.

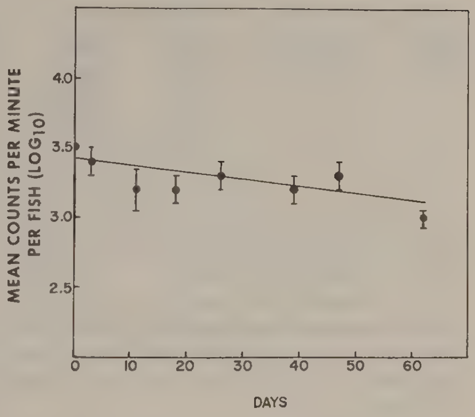

FIGURE 2.—Cobalt 60 remaining in flounder held in flowing sea water, after they had been marked in sea water containing 1.0 μc cobalt 60 per ml (Experiment 6, Table 2). Vertical lines are one standard deviation.

component of the curve (–0.01279) was used to calculate the effective half-life (23 days) and the biological half-life (25 days). Increasing the amount of cerium 144 in the water from 0.4 to 1.0 μc per ml of sea water did not increase significantly the amount of cerium accumulated by the fish in 24 hours.

The amounts of cerium 144 accumulated by the fish from food and from water were compared to determine the best source. Nauplii of the brine shrimp, *Artemia salina*, were made radioactive by placing them in water containing cerium 144 (Experiment 4, Table 1). After 24 hours the nauplii were removed, rinsed in nonactive sea water, and fed to the fish. After the feeding period, contained activity was measured and the fish were placed in nonactive water. A *t*-test comparing the logarithms of the mean counts per minute of cerium 144 accumulation from water (Experiment 2) and from food (Experiment 4) in 24 hours showed that, under the conditions of the experiments, the water source gave counts per minute per fish that were significantly higher at the 1% level.

Flounder were marked in sea water containing 0.01 μc (Experiment 5) or 1.0 μc cobalt 60 per ml (Experiment 6, Table 2). Fish marked in the lower concentration could not be distinguished from controls after remaining in flowing sea water for 26 days, but those marked in the higher concentration retained 29% of the original activity after 62 days in flowing sea water and were easily distinguishable from unmarked fish. The slope of the regression line of the retention curve (Figure 2) was –0.0049; the effective half-life of cobalt 60 was 61 days and the biological half-life 63 days.

To determine whether food or water was the most effective source of cobalt 60 for marking the fish, brine shrimp nauplii were labeled and fed to the fish. The mark produced by feeding the fish nauplii that had been labeled in water containing 0.01 μc per ml cobalt 60 was ineffective. When shrimp labeled in water containing 1.0 μc per ml were fed to fish (Experiment 8), 7% of the original activity remained in the fish after 55 days (Figure 3). The slope of the regres-

TABLE 2.—*Summary of cobalt 60 experiments*

Experiment number	Number of fish marked	Average weight (mg)	Method of marking	Concentration of isotope in water (μc/ml)	Marking time (hours)	Days in flowing sea water	Mean cpm/fish at end of experiment
5	10	54	Water	0.01	48	26	16
6	10	41	Water	1.00	24	62	1,086
7	10	79	Food	0.01	48	3	32
8	10	93	Food	1.00	24	55	531

sion line (Figure 3) was calculated to be –0.017, the effective half-life 17 days, and the biological half-life 17 days.

The difference between the amount of cobalt 60 accumulated from food (Experiment 8) and the amount accumulated from water (Experiment 6) was not significant (*t*-test; 5% level).

MARKING WITH STABLE ISOTOPES

The fish in these experiments were marked in water containing increased amounts of stable cobalt. After 48 hours in this water the fish were removed, rinsed in sea water, and weighed. One-half of the fish were held alive in flowing sea water for use at a later date; the other half were killed by placing them in vials containing 2 ml of 10% formalin solution. The vials were sealed and irradiated in the reactor at North Carolina State University. Groups of five flounders previously held in the following concentrations of cobalt were irradiated for 10 kw hours: (1) control, (2) 0.031, (3) 0.061, (4) 0.122, (5) 0.244, (6) 15.62, (7) 31.3, and (8) 62.5 μg of cobalt per ml of sea water.

After irradiation, fish were returned to the laboratory and held in a lead vault until radionuclides with short half-lives, such as sodium 24, had decayed. The fish then were removed from the vials, rinsed in distilled water, and placed in new plastic containers. The cobalt 60 in the fish was measured in a 512-channel gamma spectrometer.

No difference in cobalt 60 content existed between the unmarked fish and the fish held in 0.244 μg of cobalt per ml before irradiation (Figure 4). There was, however, an obvious difference between the fish marked in water containing 15.62 μg of cobalt per ml and the control fish (Figure 5), indicating that the increased cobalt in the water was sufficient to mark the fish. For a statistical comparison, each marked and unmarked fish was placed in a separate plastic container for measurement of contained activity. The comparison (Dunnett, 1955) indicated that fish marked in water containing 15.62, 31.3, and 62.5 μg cobalt per ml had significantly more cobalt 60 than control fish. Therefore, at the time the fish were removed from the concentrations of cobalt, it was possible to distinguish them from the control fish.

To determine the period of time the mark could be detected, the fish (previously marked in water containing 15.62, 31.3, and 62.5 μg cobalt per ml) were held in flowing sea water for 36 days before irradiation. The procedure described previously was used to determine if the marked fish could be distinguished from the unmarked fish. As before, the differences between the mean values for the marked fish and the mean values for the control fish were significant at the 1% level. On the basis of the activity in each individual, however, it would have been difficult to dis-

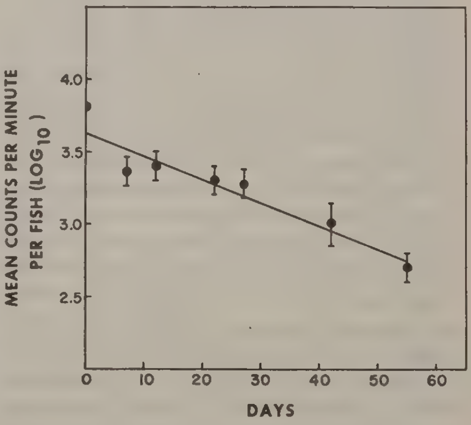

FIGURE 3.—Cobalt 60 remaining in flounder held in flowing sea water after they had been marked by feeding on brine shrimp that had been held in water containing 1.0 μc cobalt 60 per ml (Experiment 8, Table 2). Vertical lines are one standard deviation.

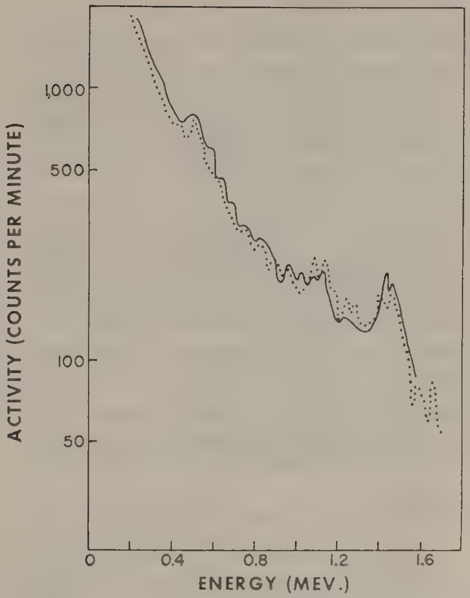

FIGURE 4.—Comparison of gamma spectra of flounder containing a "natural" level and an increased level of cobalt. The level of cobalt in flounder was increased by uptake from water containing 0.244 μg cobalt per ml. Solid line represents the "natural" level of cobalt and broken line the increased level.

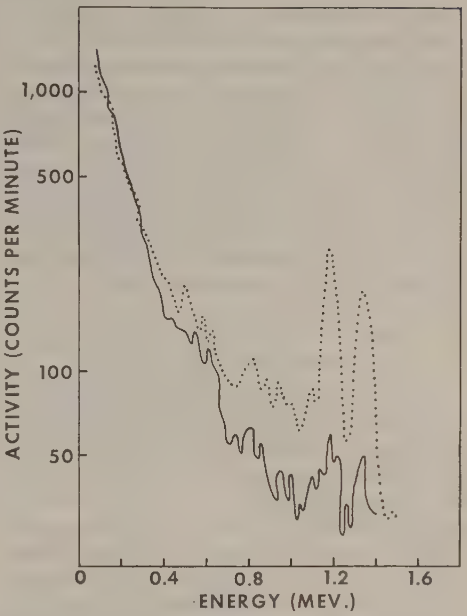

FIGURE 5.—Comparison of gamma spectra of flounder containing a "natural" level and an increased level of cobalt. The level of cobalt in flounder was increased by uptake from water containing 15.62 μg cobalt per ml. Solid line represents the "natural" level of cobalt and broken line the increased level.

tinguish the marked fish in a mixture of marked and unmarked fish under field conditions.

POTENTIAL DANGER TO MAN OF FISH MARKED WITH CERIUM 144 OR COBALT 60

The transfer of radioactivity from fish marked with radioisotopes to other organisms including man must be considered. The number of fish needed to give the maximum permissible body burden of any isotope can be estimated from the amount of the isotope in the fish and the maximum permissible body burden of the isotope, assuming that all of the isotope is transferred from the fish to the consumer. In man the maximum permissible body burdens for occupational exposure to cerium 144 and cobalt 60 are 20 μc and 10 μc, respectively (U. S. National Committee on Radiation Protection and Measurements, 1959). One-tenth of this amount (or 2 μc of cerium 144 and 1.0 μc of cobalt 60) is the permissible level for the general public. Fish marked in water containing 1.0 μc cerium 144 per ml averaged 0.4 μc per fish immediately after they were marked. It would be necessary, therefore, for a person to eat five of these fish to receive the maximum permissible body burden if all the radioactivity were assimilated. Biological loss (excretion) and physical decay further reduce the dose so that 10 days after the fish were marked, it would require 222 fish to reach the permissible burden. The corresponding figures for the cobalt 60 experiments are 50 fish immediately after marking and 100 fish 11 days after marking.

The above figures are an estimation of the maximum amount of activity that theoretically could be transferred from fish to man. Actually, the amount transferred would be much less for the following reasons: (1) By the time the marked flounder reached edible size, only a small part of the activity would remain due to physical decay and biological loss of the isotope; (2) it is not likely that after a year or two, any person would eat more than one of the marked flounder; (3) a person generally does not eat the entire fish, *i.e.*, radioactivity associated with bones, scales, and intestines would not be transferred to man; and (4) if the marked post-larval fish were not eaten by man but instead passed through several steps of the food chain, activity would be lost at each trophic level, since radioactivity associated with undigestible parts would not be transferred.

CONCLUSIONS ON VALUE OF MARKING WITH RADIOACTIVE ELEMENTS

Both cerium 144 and cobalt 60 were found to be suitable marks for larval fish in these experiments. The effective half-life of cerium 144 obtained from water was 24 days, whereas the effective half-life of cobalt 60 obtained from water was 61 days. Under the conditions of these experiments, the mark (either cerium or cobalt) was retained for a longer period of time when obtained from water. Increasing the concentration of cerium 144 in the water did not produce a measurable increase in the accumulation of this isotope by the fish. Increasing the concentration of cobalt 60 in the water, however, increased accumulation of this isotope.

Significantly increased levels of cobalt were detectable by activation analysis 36 days after fish were marked in sea water containing 15.62, 31.3, or 62.5 μg of stable cobalt. Although the difference between the means of marked and control fish was significant, the actual amount of cobalt per fish was not increased sufficiently to be useful in a field experiment where marked individuals would have to be selected from large numbers of unmarked fish. Thus, the results presented in this paper suggest that marking fish by increasing their stable cobalt content and using activation analysis for detecting the mark is possible, but more of the mark would be required to be incorporated into the fish before the method could be used in the field.

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Metabolic Rates of Estuarine Fish

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The resting metabolism of pinfish (*Lagodon rhomboides*), black sea bass (*Centropristes striatus*), Atlantic croaker (*Micropogon undulatus*), and oyster toadfish (*Opsanus tau*) was measured in the laboratory by means of a flowing-water respirometer. Resting metabolism was related to body weight by the equation $Q = aW^k$, where Q is the metabolic rate, W is the weight of the animal, and the values of a and k are constants derived from experimental data for a species. Some investigators also have stated that k values of various species do not vary significantly from 0.8. This value for k has been used to calculate the resting metabolism of certain species of fish when a was determined experimentally. In my investigations the value of k fluctuated significantly between species. The value 0.8 cannot be used as a constant in calculating metabolic rates for all species of fish for reasons discussed.

Reprinted from *The ASB Bulletin*,
Vol. 14, No. 2, April 1967, p. 31.

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pp. 850–852

Color Changes of Pelagic Prejuvenile Goatfish, *Pseudupeneus grandisquamis,* After Confinement in a Shipboard Aquarium

John R. Hunter

COLOR CHANGES OF PELAGIC PREJUVENILE GOATFISH, *PSEUDUPENEUS GRANDISQUAMIS*, AFTER CONFINEMENT IN A SHIPBOARD AQUARIUM.—Juvenile to adult mullids, *Pseudupeneus grandisquamis* (Gill), are found near shore in shallow water (2–50 fms) along the Pacific coast from the Gulf of California to northern Peru (Hildebrand, 1946; Richard H. Rosenblatt, pers. comm.). Prejuveniles (as defined by Hubbs, 1958), on the other hand, are pelagic and are found ten or more nautical miles from shore. Color differences between the prejuveniles and adults are marked. The pelagic prejuveniles are bluish-green above and silvery below; the adults are red dorsally and laterally and shade into pink ventrally (Hiyama, 1937).

Characteristically, fish in the prejuvenile stage change rapidly into a juvenile stage which usually resembles the adult (Hubbs, 1958). I noticed during several cruises in Costa Rican waters that if pelagic prejuvenile *P. grandisquamis* were placed in a shipboard tank, they often began to change color rapidly, and within a few days attained a color phase different from that of either the adult or prejuvenile. In April and May 1966, I was able to repeat my observations and record the information on these color changes.

The transformation of the prejuvenile goatfish of the western north Atlantic has been described from preserved specimens (Caldwell, 1962) and descriptions of the transformation of live prejuveniles of other families exist (Breder, 1944, 1949).

All *P. grandisquamis* were from the same locality about nine miles southwest of Punta Guionos, Costa Rica (9°45′ N, 85°39′ W, 100 fms). Prejuvenile fish were captured either in a small purse seine which was set around moored objects (Hunter, Aasted, and Mitchell, 1966) or were collected in a dipnet at night beneath a light. The fish were placed in a 50-gal shipboard glass aquarium and fed frozen brine shrimp. The coloration and habits of the fish were recorded daily and color photographs were taken of the fish in the aquarium. Fish were kept in the aquarium two to nine days; the date they were removed, measured, and preserved depended upon the state of color change in the group of fish in the tank and the availability of new fish for observation.

Upon capture the top of the head, back, and upper portion of the sides was blue-green, the lower portion of the sides and head was silvery. A narrow gold to silver stripe extended through the blue-green area of the sides from the posterior margin of the eye to the tail. The iris of the eye was white with a gold ring around the pupil. The fins were transparent.

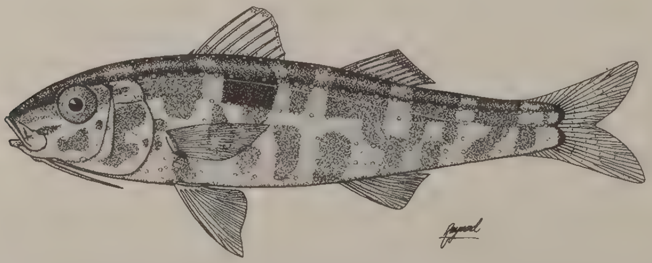

Fig. 1. Live coloration of a juvenile *Pseudupeneus grandisquamis* after confinement in a shipboard aquarium for from two to three days.

The first color change was the appearance of a reddish-brown rectangular spot on the sides. Later this spot lengthened and formed a lateral stripe, faint pink patches began to appear on the sides, and noticeable dark blue-green barring appeared in the blue-green dorsal area. If the fish was held in a net in the tank the pink patches faded to silver, the brown lateral stripe disappeared, and the fish was indistinguishable from a freshly captured specimen. Not until the dorsal bars and their interspaces turned brown did the fish lose the ability to change back to the original pelagic coloration. Only minor color changes occurred after the appearance of the brown dorsal bars. Therefore, this stage was used to judge differences in the rate of color change among individuals of different sizes. The coloration of fish at the brown-barred stage is shown in Fig. 1 and is described below.

The dorsal surface of the head and the back had eight brown bars separated by seven tan spaces. A lateral stripe of brownish-orange began at the snout, passed through the eye, and ended at the base of caudal fin. The dorsal bars extended through but not past the lateral stripe. The color of the bars changed in the lateral stripe from the dorsal color, brown, to a burnt sienna or reddish-brown. The third dorsal bar was much darker than the rest of the bars in the region of the lateral stripe and formed a dark rectangular spot. Below the lateral stripe the body was yellowish-white to milky-white with large irregular salmon-red patches. The iris of the eye was salmon-red with a gold ring around the pupil. Dorsally, a row of brilliant blue spots began at the nape, ran just below the dorsal fins and ended at the tail. There were also six rows of blue spots on the sides; the first row ran just above, and the second row just below the brownish-orange lateral stripe, and the other four rows were less prominent and were below the lateral stripe. Brilliant blue irregular streaks and spots were present on the sides of the head but formed no regular pattern. The dorsal fins were transparent except for distal and basal bands of brownish pigment; the caudal fin was yellowish with brown pigment at the base; the pectoral and anal fins were transparent; and the pelvic fin was transparent except for a milky coloration on the base and along the leading and medial margins. The barbels were milky-white. After the fish had the above coloration, only minor changes occurred: a spreading of the milky coloration on the pelvic fins; an increased reddening of the salmon-red patches; and the formation of three faint yellow stripes below the brownish-orange lateral stripe.

Table 1. Color Change of *Pseudupeneus grandisquamis* after Confinement in a Shipboard Aquarium. (Measured at end of captivity.)

Standard Length (mm)	State of Color Change at End of Captivity Period			Days in Captivity	Days Required for Change to Brown-barred Color Phase
	Brown-barred Color Phase	Partial Change	No Change		
59.6	x			9	2
59.2	x			3	3
59.1	x			5	2
58.5		x		6	–
58.4	x			2	2
58.1	x			3	3
58.0	x			3	3
57.5	x			5	2
57.4	x			9	2
57.0	x			3	3
56.9		x		7	–
56.6		x		7	–
56.6	x			3	3
56.5	x			5	2
56.4			x	7	–
55.8		x		7	–
55.5	x			3	3
55.5		x		7	–
55.5		x		7	–
55.0			x	7	–
54.6	x			3	3
54.4	x			3	3
54.4	x			3	3
54.3		x		7	–
54.2		x		7	–
53.5	x			3	3
53.4		x		4	–
53.0	x			3	3
52.9	x			9	2
52.2	x			3	3
51.3			x	7	–
51.1		x		2	–
50.7	x			3	3
49.9			x	7	–
48.9			x	4	–
48.1			x	4	–

The brown-barred stage either was attained after two to three days in captivity or did not appear during the time the fish were in the tank, usually four to seven days (Table 1). The mean SL was 55.9 mm for fish which showed this change, and 53.8 mm for fish which either failed to change color or showed only a partial change. Statistical comparison of the data grouped in this manner showed a difference at $P = 0.05$.

When placed in the tank, prejuveniles did not settle immediately to the bottom and assume the benthic habits of the adult. Bottom-dwelling habits were assumed, however, long before color transformation was complete. Records of two fish show this behavior. Two prejuveniles that were placed in the tank at 2230 hr immediately formed and remained in a school 25–50 cm above the bottom. At 0730 the next day both fish had a reddish-brown rectangular patch on their sides beneath the first dorsal fin; no further color changes occurred during the day. The fish remained in a school and contacted the bottom only briefly; between 0730 and 0735 one fish remained on the bottom for 6.0 and the other for 7.5 sec. Between 1130 and 1135, however, one fish spent 259 sec and the other 77 sec on the bottom; and between 1600 and 1605 both fish remained on the bottom. During the remaining period in captivity (about five days) they left the bottom only briefly to dart to new positions in the tank.

Ken Raymond prepared the drawing, and Frederick H. Berry and Richard H. Rosenblatt read the manuscript.

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John R. Hunter, *Bureau of Commercial Fisheries Tuna Resources Laboratory, La Jolla, California* 92037.

TURBULENCE AND PRODUCTIVITY NEAR ST. VINCENT ISLAND, B. W. I. A-PRELIMINARY REPORT[1]

by

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Miami, Florida 33149

Abstract: Tuna schools and bird flocks were found to be concentrated in an area west of St. Vincent Island. Plankton displacement volumes and primary productivity in the upper mixed layer of this area were higher than in the Atlantic. Bathythermograph data revealed the presence of turbulent eddies. The increased productivity of this area is possibly a consequence of downstream turbulence on the Caribbean side of St. Vincent Island.

THE description of ecological relationships between pelagic fishes and oceanic features is one of the major objectives of marine fishery research. During cruises of the U. S. Bureau of Commercial Fisheries vessels *Undaunted* and *Geronimo* in the eastern Caribbean Sea, in March and April 1966, the association between schools of skipjack tuna (*Katsuwonus pelamis*) and features of their environment was studied in the vicinity of St. Vincent Island, B. W. I. The distribution of the tuna schools appeared to be related to the presence of turbulence and biological enrichment west of the island.

Turbulent structures in the upper oceanic stratosphere during the survey period are shown in figure 1A, B, and C. The 24° C isothermal surface, rather than the thermocline, was chosen to represent these structures because two distinct, overlapping thermoclines were evident in the area.

On March 27 and 28, an anticyclonic eddy was centered about 60 nautical miles west of St. Vincent (fig. 1A). Portrayal of this isothermal topography is somewhat conjetural because the location of most of the bathythermograph stations was determined by sightings of tuna schools or bird flocks and was not optimal for the description of the temperature field.

From March 31 through April 3 part of a cyclonic eddy was present in the northeastern half of the station grid west of St. Vincent (fig. 1B). Data from five stations suggested the possibility of an anticyclonic eddy beyond the western edge of the grid. This topography may have been the result of southwesterly

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[1] Contribution No. 42, Tropical Atlantic Biological Laboratory, Bureau of Commercial Fisheries, Miami, Florida, 33149.

Carib. J. Sci. 6 (3-4). Sept.-Dec. 1966.

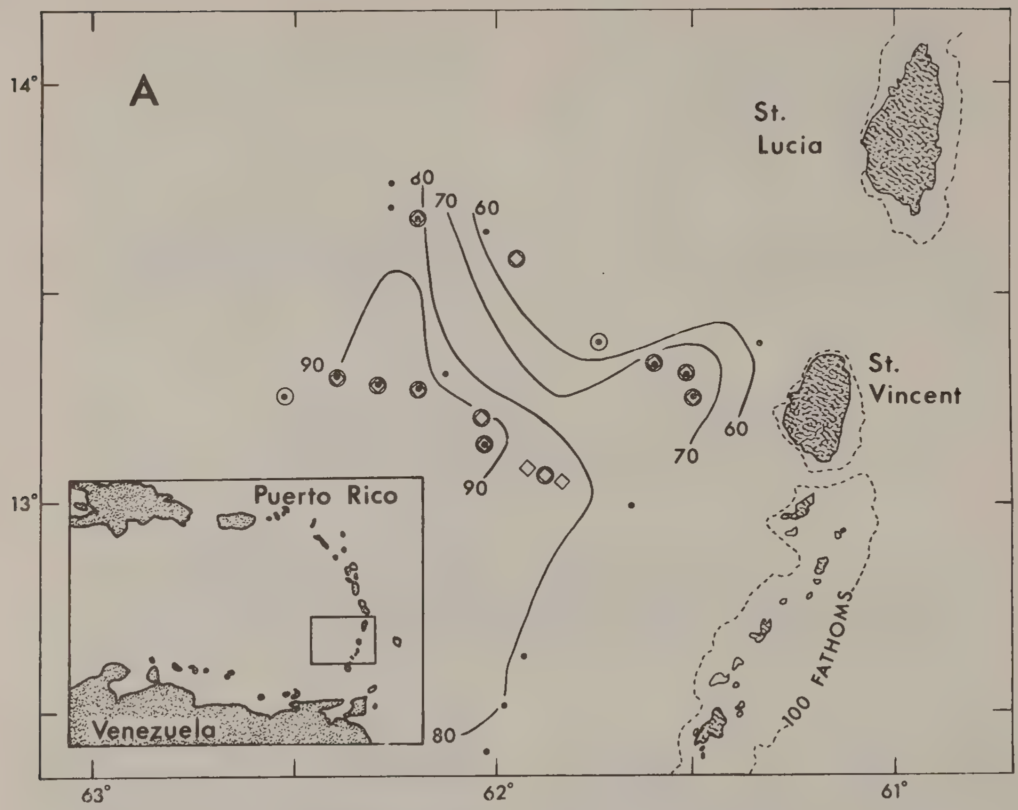


FIG. 1. Isothermal topography and sightings of fish schools and bird flocks west of St. Vincent on (A) March 27-28, 1966, (B) March 31-April 3, (C) April 8-14, and (D) east of St. Vincent on March 29-30. Bathythermograph stations are indicated by dots, sightings of bird flocks by diamonds, and sightings of tuna schools by circles. The depth (meters) of the 24° C isotermal thermal surface is shown by solid lines (by numbers in D), and the 100-fathom contour by broken lines.

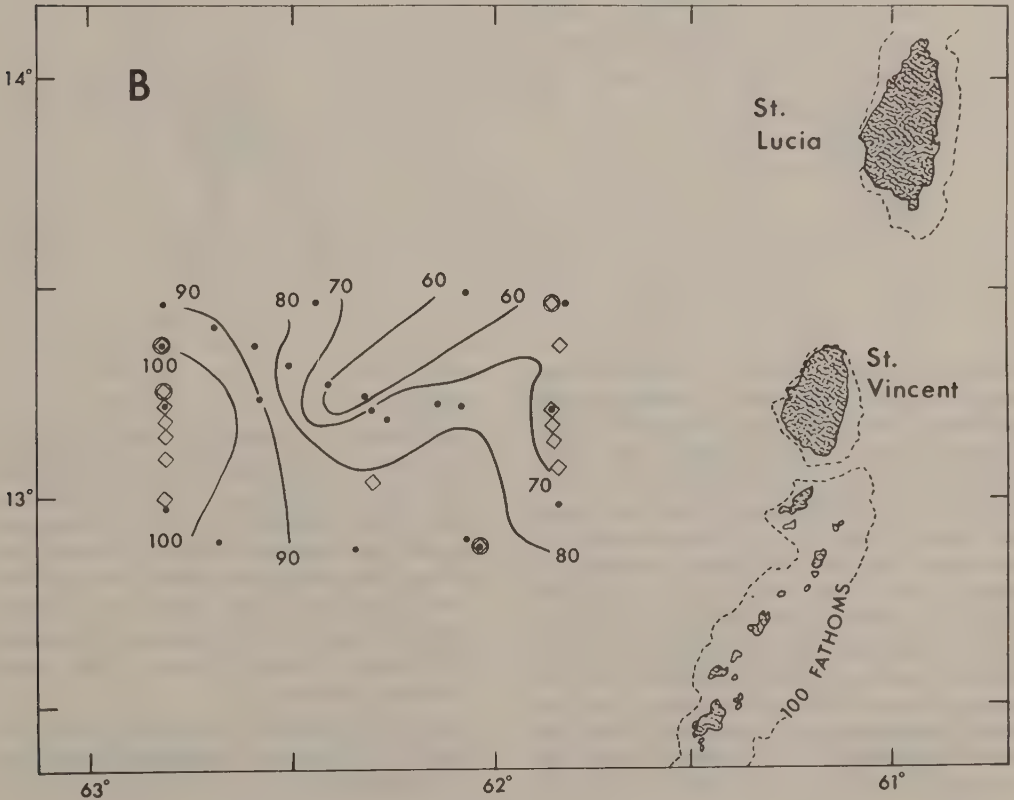
movement of the anticyclonic eddy shown in figure 1A. If so, the displacement was about 30 nautical miles in 4 days — a speed about one — tenth of the average surface current speed given for this area by Wüst (1964).

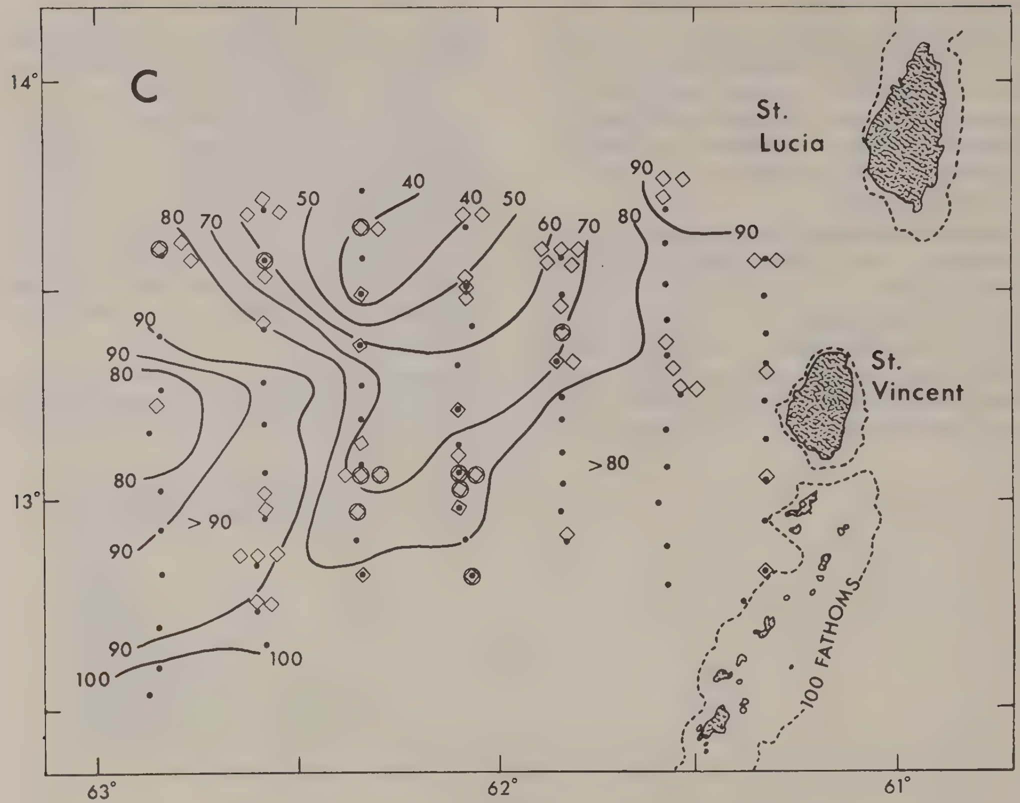
A larger, more closely spaced grid of stations west of St. Vincent, occupied from April 8 through April 14, clearly showed part of one cyclonic eddy occupying most of the field and a portion of another on the western edge (fig. 1C). The principal eddy may have resulted from intensification of the eddy of figure 1 B, or may have been a different one. Westward displacement of turbulent eddies is to be expected in this area, because the surface currents near St. Vincent flow into the Caribbean from the Atlantic. The speed and constancy of the displacement are not known (except for the 30 nautical miles in 4 days suggested above). Further investigations are needed to establish the drift rate of the eddies.

East of St. Vincent, on March 29 and 30, the 24° C isothermal surfact sloped steeply eastward, from less than 70 m to more than 150 m (fig. 1D), indicating that the current above it contained a strong northward component in the area between St. Vincent and Barbados. Insufficient temperature data were acquired to verify the presence or absence of turbulent structures.

Primary productivity and standing stock of zooplankton were higher on the Caribbean side of the Antilles arc than on the Atlantic side. Primary productivity stations were occupied each day at local apparent noon. Water samples from five standard light-intensity depths were inoculated with Carbon — 14 and incubated under simulated light — intensity levels for 24 hours. Depth — integrated carbon fixation values averaged 0.0249 gC/m^2/day for three stations east of St. Vincent and 0. 0477 gC/m^2/day for four stations west of the island. Further evidence of higher productivity on the western side of the Antilles was provided by comparison of Atlantic and Caribbean plankton hauls. The average displacement volume of plankton in oblique hauls of a 1-meter net in the mixed layer was 72 ml/1,000^3 for fuor hauls east of the island and 177 ml/1,000 m^3 for 14 hauls on the western side.

Large concentrations of bird flocks and tuna schools were found on the Caribbean side of St. Vincent (fig. 1A, B, and C). Fish schools





sampled consisted entirely of skipjack tuna, except for one mixed school of skipjack and yellowfin tuna (*Thunnus albacares*), Fish schools generally were discovered after sightings of bird flocks, which were over the foraging fish. The distributions of these bird flocks are shown in figure 1. It was impractical to investigate every bird flock while occupying the station grid; some flock sightings shown in figure 1C probably also indicate fish schools. Bird species seen most frequently and in the greatest numbers were: sooty tern (*Sterna fuscata*); red-footed booby (*Sula sula*); bluefaced booby (*Sula dactylatra*); and frigate bird (*Fregata magnificens*). Less common were the pomarine jaeger (*Stercorarius pomarinus*), noddy tern (*Anous stolidus*), and various shearwaters.

In contrast with the heavy concentrations of bird flocks and fish schools along the Caribbean side of St. Vincent, only one bird flock was sighted, and no fish schools were observed, between Barbados and St. Vincent (fig. 1 D). Few flocks and schools were seen on the Atlantic side of the entire Lesser Antilles island arc; only 11 small scattered fish schools were sighted during 14 days in the period February 24-March 21.

We hypothesize that the higher productivity west of St. Vincent is significantly related to the turbulent eddies observed there. Cyclonic eddies, if quasi-geostrophic, are capable of increasing primary productivity by bringing nutrient-rich water up into the photic zone. A test of this hypothesis must await further analysis of our physical, chemical, and biological data, and the results of future investigations which may produce a more detailed description of the turbulent structures and a better definition of the temporal changes in relevant environmental variables.

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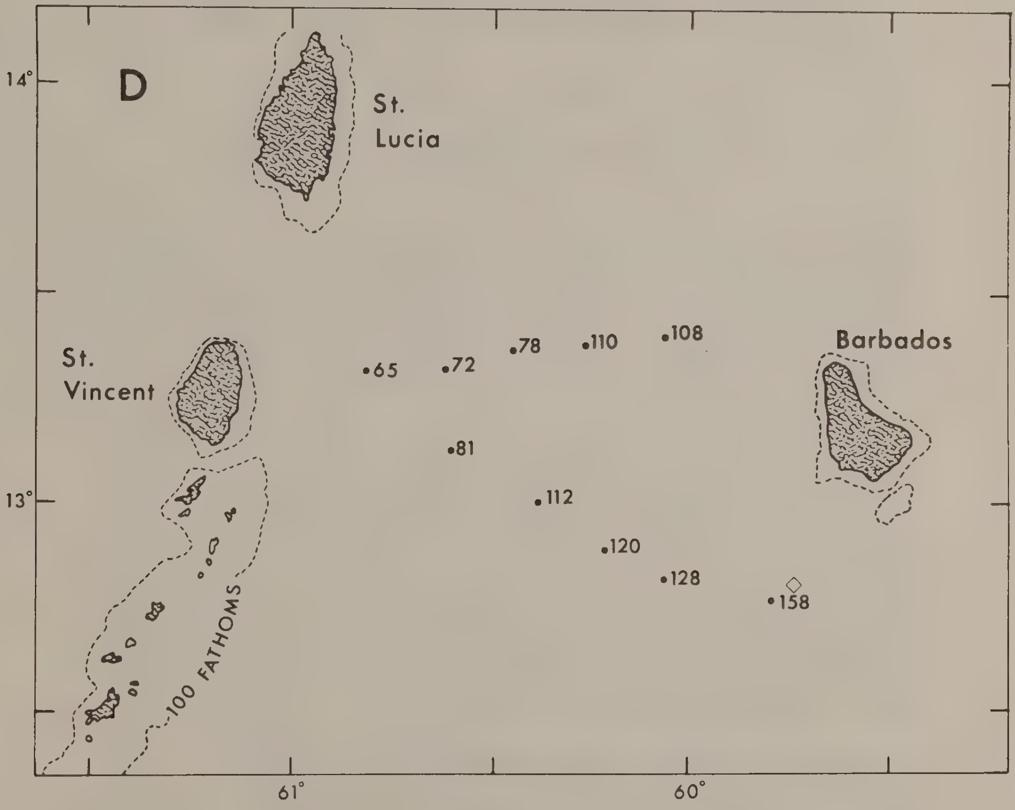
D
14°
13°
61°
60°
St. Lucia
St. Vincent
Barbados
100 FATHOMS
65
72
78
110
108
81
112
120
128
158

Reprinted from
MARINE BIO-ACOUSTICS
Volume 2
Proceedings of the Second Symposium on Marine Bio-Acoustics
held at the American Museum of Natural History, New York, April 13–15, 1966
PERGAMON PRESS – OXFORD & NEW YORK – 1967

RESPONSE OF YELLOWFIN TUNA *(THUNNUS ALBACARES)* TO UNDERWATER SOUND*

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Knowledge of hearing thresholds and of frequencies audible to the tuna is needed to identify the oceanic sounds important to these schooling, pelagic marine teleosts. Identification of such sounds should provide insight about the sensory systems used by tuna to capture prey, avoid predators, identify conspecifics, and reproduce. It should help in devising new methods of capture.

Little is known, however, about hearing in pelagic teleosts. Miyake (1952) attempted to attract or repel yellowfin tuna *(Thunnus albacares)* and little tunny *(Euthynnus affinis)* with continuous sounds from 100 to 70,000 Hz but achieved no positive results. Other reports on hearing in marine fish have been concerned with fish that either lived in reefs, inshore or in association with the bottom, or were about hearing in sharks. These have recently been reviewed by Tavolga (1965). There are no curves of hearing that describe response thresholds and frequencies audible to pelagic teleosts such as those described by Tavolga and Wodinsky (1963, 1965) for nine species of inshore and reef fishes.

This report describes hearing thresholds and frequencies audible to yellowfin tuna during experiments at the tuna behavior facility, U.S. Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii.

EXPERIMENTAL ANIMALS AND TANK

Data were obtained from two yellowfin tuna, 50 and 60 cm in fork length. They were captured and transported to the shoreside laboratory using Nakamura's method (1962). At the time of testing, the fish had been in captivity from three to ten months. Experiments were conducted in a covered circular tank 7.2 m in diameter and 1.2 m deep that was supplied with salt well water. A vinyl-impregnated dacron liner supported by an aluminum retaining ring formed the tank. It rested on a footing of beach sand 30 cm high. The sides and bottom were acoustically insulated with mats 38 mm thick made of rubberized pig and horse bristles. An observation booth adjacent to the tank housed electronic equipment and allowed the observer to conduct the experiments unseen by the yellowfin.

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* Hunt E. Johnson helped conduct the experiments. John J. Magnuson and Eugene L. Nakamura offered advice and encouragement. Tamotsu Nakata prepared the figures.

EQUIPMENT USED TO PRODUCE AND MEASURE SOUND

One electronic system was used to produce the sounds, another to measure the sound level (Fig. 1). Sounds were generated by a Hewlett–Packard model 2AB *audio oscillator and were keyed via a photoconductive resistor switch. Sound levels were changed with a Hewlett–Packard model 350D attenuator (range: 110 dB) by 1, 5, or 10 dB steps. An amplifier from a Magnecord PT6–BM tape recorder was used to prevent distortion of frequencies below 100 Hz. Above 100 Hz, an undistorted signal was obtained by increasing the gain of the oscillator. Wave form was inspected by means of an oscilloscope (Hickok 770) and only undistorted sine wave signals

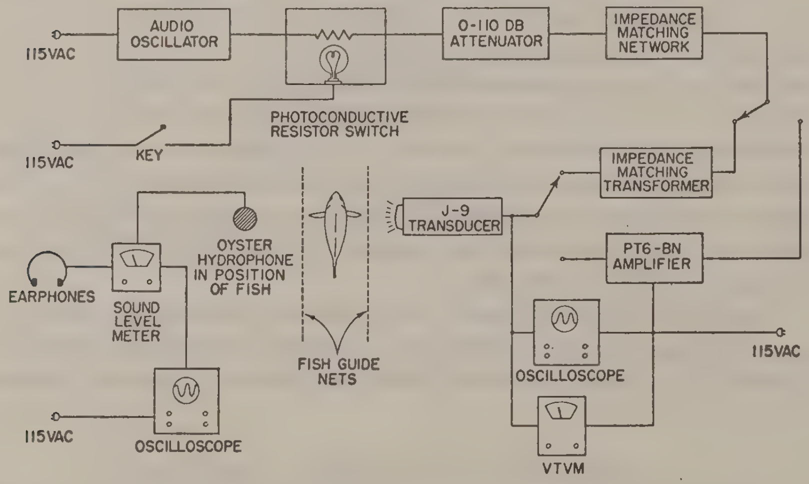
115VAC
AUDIO OSCILLATOR
0-110 DB ATTENUATOR
IMPEDANCE MATCHING NETWORK
PHOTOCONDUCTIVE RESISTOR SWITCH
115VAC
KEY
IMPEDANCE MATCHING TRANSFORMER
OYSTER HYDROPHONE IN POSITION OF FISH
J-9 TRANSDUCER
PT6-BN AMPLIFIER
EARPHONES
SOUND LEVEL METER
FISH GUIDE NETS
OSCILLOSCOPE
115VAC
115VAC
OSCILLOSCOPE
VTVM

FIG. 1. Block diagram of equipment used to produce and measure the level of underwater sounds.

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* Trade names referred to in this publication do not imply endorsement of commercial products.

were used. The J–9 underwater transducer (Chesapeake Instrument Co.) had a frequency response of 40 to 20,000 Hz. It was mounted permanently on a wooden strut and was lowered to the same position for each experiment.

Sound levels were measured with a Clevite CH–15 oyster hydrophone (frequency response flat from 50 to 2000 Hz) connected to a General Radio 1551–C sound level meter (frequency response, 20 to 20,000 Hz). To measure airborne sounds, a microphone is used with this sound level meter. When a hydrophone must be used in place of the microphone, sound levels shown by the meter do not indicate the true sound levels because of differences in sensitivity between the hydrophone and microphone. The true sound levels were obtained by adding a correction factor to the sound level shown on the C scale of the meter. This factor compensated for the difference in sensitivities and resulted in the sound level referred to 0.0002 μbar. The level referred to 1 μbar was then calculated by subtracting 74 dB. Sound pressure levels in this paper are given in reference to 1 μbar unless otherwise stated. Sound levels at thresholds were not measured directly because interference from a nearby radio antenna caused spurious readings when the meter sensitivity was increased beyond a certain point. The interference did not affect the outgoing signal.

Background Noise Levels

A U.S. Navy AN/PQM–1A Noise Measuring Set with DT–99 hydrophone was used to make a spectrum analysis of the level of background noise in the tank (Table 1). Frequency response of this equipment is 20 to 40,000 Hz. Measurements were made from 0100 to 0300 hours when the nearby radio antenna was not transmitting. The hydrophone was placed 50 cm from the transducer and the pumping system was shut down, as it was during the experiments. Winds were about 5–7 knots across the surface

TABLE 1. BACKGROUND NOISE IN THE EXPERIMENTAL TANK. LEVELS SHOWN ARE FOR TOTAL NOISE IN THE BANDWIDTH

Bandwidth (Hz)	Pressure levels (dB/1 microbar)	
	Measurement No. 1 (XI–15–64)	Measurement No. 2 (XI–22–64)
20–100*	−1*	−1*
100–316	−14	−16
316–1000	−26	−26
1000–3160	−24	−28
3160–10,000	−26	−25

* Estimated

of the tank. The estimated background noise for the 20 to 100 Hz bandwidth was calculated by combining pressure levels measured on the different bandwidths of the noise measuring set (Bureau of Ships, n.d.).

Highest noise levels occurred from 20 to 100 Hz, where the average pressure level was −1 dB. The predominance of low frequencies probably results from the noise due to surf on the nearby reef front. The frequency distribution and pressure levels of the background noise are similar to sounds produced by a sea with waves up to 1.0 m high, as in a sea state between 0 and 2 (Fig. 2).

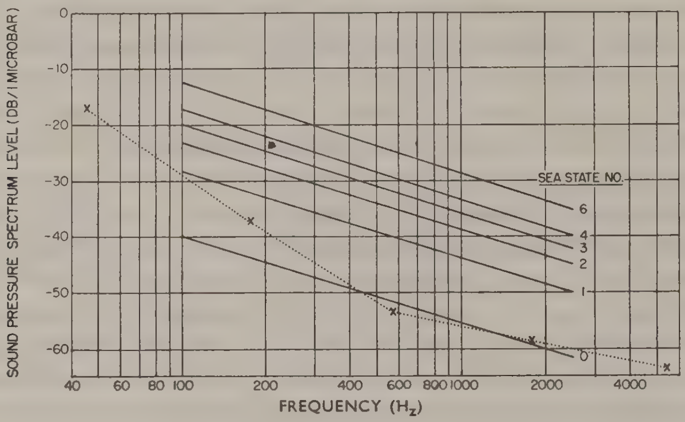


FIG. 2. Pressure levels of background noise in the experimental tank (broken line) compared with Knudsen curves of ambient noise in the open sea (solid line). Noise levels given in 1 cycle per second bandwidth. Dotted line values converted from data given in Table 1. Knudsen curves were taken from Wenz, 1964.

Variations in the Sound Field near the Transducer

The main causes of variation were assumed to be from: (1) a highly directional transducer beam pattern, (2) standing waves, (3) distance from the source. Beam patterns were determined by measuring sound levels at a distance of 53 cm along an arc 90° to either side of the transducer. Measurements were made every 15° with the hydrophone at the same depth as the transducer. Frequencies tested were 50, 100, 300, 500, 800, 1100, and 1500 Hz.

The results showed two things. First, except at 300 Hz, beam patterns were almost omnidirectional over the 180° arc. In the area of primary interest, 30° to either side of the transducer, they were omnidirectional. At 300 Hz, the response curve was down 7 dB 30° to the left, but the change was gradual and the shape of the curve did not change past 30°. Second, the absence of irregularly occurring variations in the patterns indicates that interference from standing waves was negligible, except possibly at 300 Hz. Thus normal transmission losses due to distance were the main cause of differences in sound level between points in the sound field.

METHOD OF CONDUCTING THE EXPERIMENTS

The yellowfin was first conditioned to associate sound from the transducer with a food reward. Next it was taught to (1) swim around the tank and pass the underwater transducer at a given distance (Figs. 3, 4), (2) turn left between two nets if sound was projected, and (3) swim straight ahead past the transducer if sound was not projected. The food reward was tossed to the yellowfin after a correct response was made to projected sound (Fig. 3). Once trained, the yellowfin would make very few mistakes. In one instance,

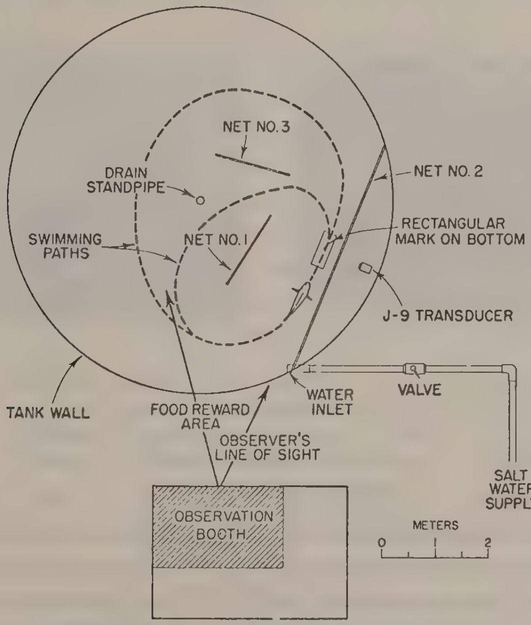
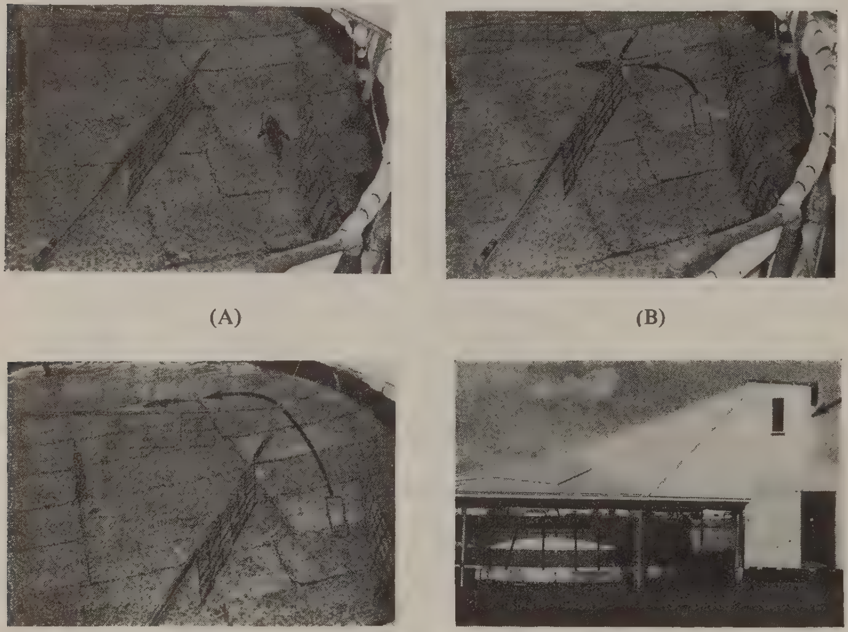

NET NO. 3
DRAIN STANDPIPE
NET NO. 2
RECTANGULAR MARK ON BOTTOM
SWIMMING PATHS
NET NO. 1
J-9 TRANSDUCER
TANK WALL
FOOD REWARD AREA
WATER INLET
VALVE
OBSERVER'S LINE OF SIGHT
SALT WATER SUPPLY
OBSERVATION BOOTH
METERS
0
1
2

FIG. 3. Diagrammatic view of experimental facilities.

it made only five mistakes in 120 consecutive trials. Untrained yellowfin usually ignored the sounds when conditioning first began, but on two occasions the yellowfin, during the first hour of conditioning, responded instantly to a loud 500 Hz sound with a dash across the tank.



(A) (B)

(C) (D)

FIG. 4. Trained responses of yellowfin tuna, holding tank and observer's booth. A, Yellowfin in front of transducer. B, Yellowfin turns sharply between nets in response to sound. C, Yellowfin goes straight ahead and around pool when sound is below threshold or no sound given. D, Outside view; arrow points to observer's both.

A modification of the method of limits (Andreas, 1960) was used to determine threshold levels. With this method the level of a stimulus is lowered by a standard amount on successive trials until the subject no longer responds. Threshold is defined as a value between the stimulus level when the subject fails to respond and the next higher level tested. In the yellowfin experiments, the level of the sound stimulus was lowered by 5 dB every 20 trials, until the yellowfin made 10 mistakes in any group of 20 trials. This level was considered to be below threshold. Threshold was then defined as the level halfway between the 50 per cent error level and the level 5 dB higher, i.e. the level during the previous 20 trials.

Each group of trials included 10 with the sound and 10 without; the order of presentation was chosen at random. At each frequency, the yellowfin often made no errors during the first two or three groups of 20 trials, especially if the starting sound level was well above threshold. As the sound level was lowered, the percentage of errors increased toward 50 per cent. The starting sound level was chosen by dropping the level in successive trials to make a quick approximation of the threshold. It was usually 30 dB above thresholds from 200 to 800 Hz, and 15—20 dB above threshold at frequencies below 200 Hz and higher than 800 Hz. Each day 5 to 10 min. of retraining before testing was required to produce consistent responses. Once, after a 55-day lapse between trials, the yellowfin responded the first time to the sound and by 20 trials was turning to the food reward area.

The yellowfin did not always turn sharply left in response to the sound, but sometimes swam in a looping turn before passing between nets 1 and 3. The latter responses were not counted as errors. On some days the fish made figure-8 turns in response to sound, swimming past the transducer and returning between nets 1 and 2; when this happened testing was discontinued to avoid ambiguous scoring.

After testing, the sound level at threshold was determined. The hydrophone was placed in the position of the yellowfin during testing. This was usually about 50 cm from the transducer. With zero attenuation and the oscillator and amplifier outputs unchanged, the stimulus was transmitted and measured with the sound level meter. The amount of attenuation, in dB, required to bring the yellowfin to the 50 per cent error level was then subtracted from the corrected meter reading. The threshold was then calculated as previously explained.

RESPONSE OF YELLOWFIN TUNA TO SOUND

A threshold curve (Fig. 5) based on data from the two yellowfin was fitted by the least squares method for a polynomial. The fish responded to sounds from 50 to 1100 Hz, with the most sensitive responses occurring between 300 and 500 Hz. Thresholds at the highest and lowest frequencies were approximately 40 dB higher than at 500 Hz. The maximum difference between replicate thresholds at any one frequency was 11 dB at 200 Hz. Thresholds below 200 Hz for both yellowfin showed no tendency to drop, despite repeated testing.

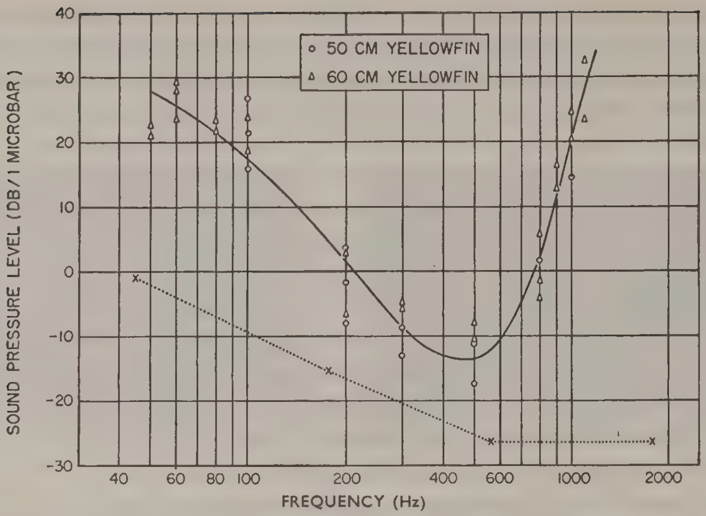


FIG. 5. Response of two yellowfin tuna to underwater sound. Dotted line indicates background noise plotted as total noise in the bandwidth from the data in Table 1.

Variations due to Movements by the Yellowfin Tuna

Variations in position of the yellowfin relative to the transducer could cause undesired inter-trial differences in sound levels. Usually the yellowfin swam by the transducer at a distance of 50 cm and with only slight variation in vertical position, about 7 to 8 cm. At 50 cm from the transducer, vertical changes of 7 – 8 cm placed the fish only slightly farther away, where the difference in sound level would be less than 1 dB. Horizontal movements were somewhat greater. A rectangular mark 18×64 cm was placed on the tank bottom in front of the transducer (Figs. 3, 4) and the sound was projected only when the yellowfin was over the rectangle. The observer, who was in a direct line with the long axis of the rectangle, could estimate the yellowfin's horizontal position within about 8 cm. The fish usually swam over the rectangle at the same spot during any group of trials or on trials held the same day. Variation between days was greater. One day the yellowfin might consistently swim over the right edge of the rectangle; on the next it might swim over the left edge. The important thing was the consistency during any group of trials. This allowed accurate placement of the hydrophone to measure thresholds. Variations in sound level due to an observer's error of 8 cm in hydrophone placement were measured to be between 1 and 3 dB. The length of time the sound was projected depended upon the swimming speed of the yellowfin. The sound began when the yellowfin's snout crossed the end of the rectangle nearest the observer. Sound ended when the yellowfin's snout crossed the rectangle's far side; in this position, a point halfway between its snout and tail was directly in front of the transducer. In one set of 25 trials, the stimulus averaged 0.9 sec, and probably did not vary more than a few tenths of a second during the tests.

Snout to Tail Differences in Sound Level

The yellowfin usually swam by the transducer at a distance of 50 cm. This meant snout to tail differences at the closest point of approach might be high because the length of the fish approximated the distance from the transducer. A uniform sound field was considered desirable so that all lateral line receptors would receive the stimulus at about the same level. Expected differences are compared with measured differences in Table 2. Except at 300 Hz, where the difference was 5 dB, the measured differences were all 4 dB or less. Considering the size of the yellowfin, differences of this order were judged relatively unimportant.

TABLE 2. EXPECTED AND MEASURED DIFFERENCES IN SOUND LEVEL BETWEEN THE YELLOWFIN'S SNOUT AND TAIL

Frequency (Hz)	Snout to tail difference (dB)	
	Expected	Measured
50	2	2
100	2	3
300	8	5
500	3	4
800	2	2
1100	2	1
1500	2	4

COMPARISON WITH OTHER SPECIES

Its lowest thresholds between 300 and 500 Hz (−13 dB, −17 dB), place the yellowfin's responses about midway among the most sensitive reported for other non-ostariophysine fishes, which have varied from −50 dB for the sciaenid *Corvina* (Maliukina, 1960) to +10 dB for the schoolmaster, *Lutjanus apodus* (Tavolga and Wodinsky, 1963). The thresholds for non-ostariophysine fishes such as the tuna are much higher than those of ostariophysines, which have their anterior vertebrae modified into ossicles linking the swimbladder and inner ear. This enhances the transmission of sound to their inner ear.

The range of frequencies perceived by yellowfin approximates those of other non-ostariophysine fishes, except the squirrelfish *Holocentrus ascensionis*, which has a frequency response as high as 2400 Hz (Tavolga and Wodinsky, 1963). Considerable differences occur between the most sensitive portion of the yellowfin threshold curve and those of other non-ostariophysines. Tavolga and Wodinsky (1963, 1965) reported the most sensitive thresholds for their fish to be at low frequencies, about 100 to 400 Hz. These thresholds were obtained after repeated testing and from them Tavolga and Wodinsky constructed what they call secondary threshold curves, as distinct from the primary curve obtained from the initial test program. Many of their secondary thresholds were 20 dB lower than the primary thresholds and their most sensitive frequencies were about 200 Hz below the most sensitive portion of the primary curves. They attributed the secondary curves to responses by the lateral line which they said occurred after the fish switched from using the inner ear. Tavolga and Wodinsky used the same procedure in all tests. In their 1963 report they stated, "We conclude that initially the fish used the less sensitive detector and, after additional experience, switched abruptly to a receptor at least 20 dB more sensitive than before. On various morphological and behavioral grounds, this phenomenon is interpreted as the utilization of two sensory modalities: the inner ear and the lateral line." In their 1965 report they modified this view somewhat by saying, "A more parsimonious explanation would be that the experience of testing makes the animals more expert in detecting and responding to the signals. This hypothesis, however, would leave unexplained the abrupt and major changes in thresholds, and the existence of plateaus in the staircase tests, all predominantly at low frequencies." Repeated testing failed to disclose such a secondary threshold curve in the yellowfin.

The level of background noise may influence responses at low frequencies. This is suggested by a comparison of background noise in the yellowfin's tank and background noise in tanks used by Tavolga and Wodinsky (Fig. 6) during experiments with *Haemulon sciurus*, the blue-striped grunt. Their tanks had a noise level usually −50 dB or less at frequencies below 300 Hz and −39 dB or less at frequencies below 1200 Hz. My tank had higher noise levels. Below about 500 Hz, the shape of the threshold curves of both yellowfin and *H. sciurus* generally followed the shape of their respective background noise curves. Above 500 Hz, both threshold curves rise sharply from the background noise curves. Presumably the background noise above 500 Hz is of secondary importance for these two species, while background noise may be the factor controlling thresholds below 500 Hz.

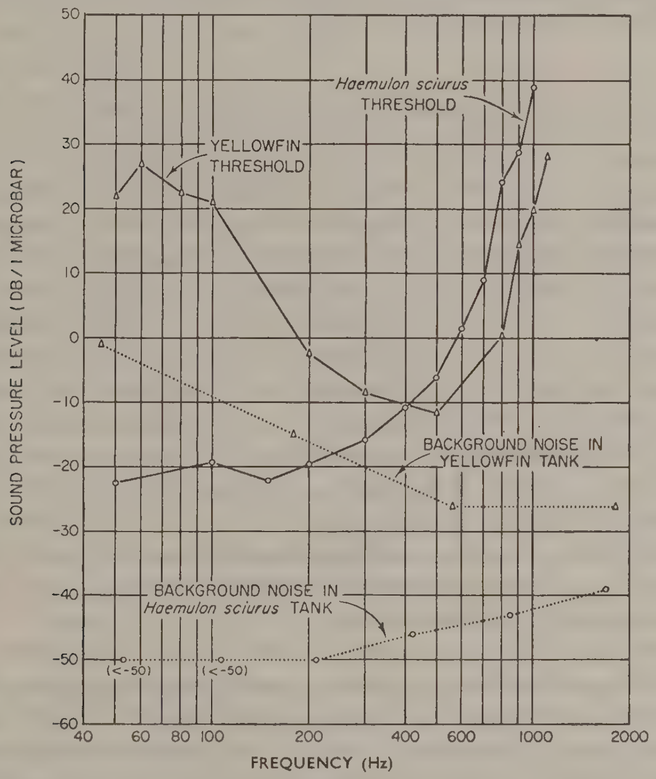


FIG. 6. Threshold curves and experimental tank background noise of yellowfin tuna and *Haemulon sciurus*. *Haemulon* curves from Tavolga and Wodinsky, 1965. Threshold curves based on mean values. Background levels are total noise in the bandwidth.

Kritzler and Wood (1961) described the threshold curve for the bull shark, *Carcharhinus leucas,* in relation to the background noise in the holding pen. The holding pen to a degree approximated the acoustic environment normally inhabited by the bull shark. They reported a mean background noise level of −14 dB, but did not give a bandwidth spectrum analysis. Assuming most of the background noise in the ocean is due to low frequencies (Wenz, 1964), then low frequencies probably caused most of the background noise level in the holding pen and may also have influenced the shark's thresholds at low frequencies. For example, the bull shark threshold at 100 Hz (the lowest frequency tested) was 27 dB above a background of −14 dB. In comparison, at 100 Hz, the yellowfin's threshold averaged 30 dB above a background of −9 dB.

DOES THE YELLOWFIN TUNA SWIM BLADDER HAVE A ROLE IN SOUND PERCEPTION?

Harris and van Bergeijk (1962) have suggested the lateral line could be stimulated by near-field displacements resulting from volume changes in the swim bladder in response to sound pressures. Thus, the yellowfin's lateral line might respond to sounds via its swimbladder. The yellowfin swimbladder might also transmit sounds to the inner ear via the vertebral column and the skull. The most anterior portion of the thin-walled swimbladder is dorsally cleft into two pockets or horns, which fit on either side of the dorsal aorta into a pit located just below the sixth vertebra (Godsil and Byers, 1944). This association between the swimbladder and the vertebral column may be greater than they say. X-ray photographs were made recently at this laboratory of eight yellowfin (56 to 77 cm fork length) shortly after their death. The X-rays showed the anterior portion of their swimbladders were close to the ventral portions of some or all of the fifth through the eighth vertebrae, not only the sixth.

On the other hand, a comparison of swimbladder sizes among tunas suggests the swimbladder is not used for sound perception, if it is assumed others hear about as well as yellowfin. Godsil and Byers (1944) cited the high variability in overall size and shape among the swimbladders of several species of tuna. The yellowfin swimbladder is about 50 per cent as long as the abdominal cavity. Comparable figures for other tunas are: bigeye *(Thunnus obesus)*, 90 per cent; albacore *(T. germo)*, 85 per cent; and bluefin *(T. thynnus)*, rudimentary in small specimens (<20 per cent), sometimes inflated in adults (>20 per cent). Several tunas, such as the skipjack *(Katsuwonus pelamis)* and the little tunny *(Euthynnus affinis)* do not even have swimbladders. If the tuna swimbladder served a function in sound perception, it ought to be a more regular structure.

ACOUSTIC ENVIRONMENT OF THE YELLOWFIN TUNA

The acoustic environment of the yellowfin may be broadly separated into two categories: self-generated sounds and sounds generated elsewhere. Miyake (1952) reported low frequency sounds produced by sudden tail movements and sounds caused by splashing against the water's surface. Timofeev (1965) has reported "knocks" made by skipjack tuna (personal communication). The "knocks" had a frequency range from 400 to 5000 Hz with the maximum intensities between 500 and 700 Hz, and 1500 and 2000 Hz. He also stated, "It should be noted that the sounds produced by tuna carry within some sort of information, since after several knocks, the school instantly—as if on command—submerged to a deeper level of the ocean and appeared again, after some time, in another location."

During the yellowfin hearing experiments, two different self-generated sounds were detected. One was a "snap" or "snap-snap", similar to the sound made by striking a wooden pencil against a table edge. It was visually correlated with the rapid closing together of the yellowfin's jaws. The other sound has been named the "unh", a grunt-like sound that occurred when the yellowfin flexed its body to avoid an obstacle. It was lower in pitch than the "snap" and similar to the sound produced by striking one's fist smartly against the heel of the palm of the opposite hand. Judging from the flexed position of the yellowfin, it seems likely the "unh" was caused by internal muscle-skeletal action. To the human ear, both seemed to contain frequencies near 500 Hz, especially the "unh". The "unh" may correspond to Timofeev's "knock".

An estimate was made of the approximate level of the "unh" based on dial settings of the sound level meter when the sound was heard. With the hydrophone 2 m from the yellowfin, one "unh" was estimated at 15 dB. If I am correct in judging the frequency content of the "unh" to be about 500 Hz, it could be used as a signal between yellowfin. A signal level of 15 dB at 2 m can be referred to a source level of about 61 dB at 1 cm. If one assumes a response threshold of yellowfin at 500 Hz to be −11 dB, then a transmission loss of 72 dB would be the maximum allowable in order for a sound of 61 dB source level to arrive at another yellowfin and still be perceived. The distance corresponding to a transmission loss of 72 dB is slightly over 40 m. If such sounds are actually used by tuna as signals, they could provide a method of rapid communication, even in large schools. For example, if the largest dimension of a school of yellowfin was 1 km, the signal need be relayed only 25 times to cover this distance. Even this might not be necessary, for once the first sound was produced and a behavioral change initiated, the rest of the school might follow visual cues.

Regarding sounds generated elsewhere, the existence of sounds that could convey information to yellowfin is well known. Moulton (1960), for example, presents spectrograms of the swimming sounds of a large school of anchovies, *Anchoviella choerostoma*, a typical type of tuna prey. A large fraction of these sounds were below 500 Hz. Moulton also shows that small *Caranx latus* and *Trachinotus palometa* produce low frequency swimming sounds. It is likely that all compact schools of small fish produce such sounds to some degree. Invertebrate food of yellowfin, such as squid, may also produce sounds near 500 Hz that might be detected by yellowfin (Iversen, Perkins, and Dionne, 1963).

SUMMARY

Two yellowfin tuna *(Thunnus albacares)* were trained to swim past an underwater transducer at a distance of about 50 cm and choose one of two possible swimming paths in response to sounds from the transducer. Thresholds of hearing for the yellowfin in response to sounds from 50 to 1100 Hz were then obtained using a modification of the method of limits. The lowest thresholds were -13 dB/μbar at 300 Hz and -17 dB/μbar at 500 Hz. Thresholds at 50 and 100 Hz were about 40 dB higher than at 500 Hz. There was no tendency for thresholds to drop with repeated testing. It is suggested that the background noise level below about 500 Hz may determine threshold levels, since the yellowfin's threshold curve from 50 to 500 Hz had the same general shape as the curve of background noise levels in the tank. The role of the yellowfin's swimbladder in sound perception and the acoustic environment of the yellowfin are discussed. Two sounds produced by the yellowfin are described; the use of one as a signal between individuals in a school of yellowfin is discussed.

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DISCUSSION

DR. ALBERS: I want to reiterate a plea that I believe Dr. Steinberg made yesterday that we need to have better tanks from the standpoint of ambient sound levels. As Mr. Iversen has pointed out, the response down in the low frequency region has probably been influenced by the ambient sound. If the ambient sound level is high, any sensing mechanism is going to sense the equivalent sound pressure over its range of sensitivity. This will be a sort of integral of the sensitivity times the sound pressure at each point in the band.

The measurement of acoustic spectral response of fish is difficult because of the low frequencies which are involved. It is difficult to maintain an adequately low ambient noise level and it is difficult to generate these frequencies as pure tones because of the possibility of the sound projector generating harmonics of the electrical signal used to excite it. In the present work, the wave form of the acoustic signal was observed on an oscilloscope and, therefore, one can be reasonably certain that the signal was a pure tone over most of the range, at least. However, to illustrate what can happen, if we assume that the measurement of response of the fish is correct at 500 Hz, it is conceivable that the entire response at 200 Hz is due to the second harmonic of the 200 Hz signal even though it is not detectable on the oscilloscope trace, since a harmonic at a level 15 or more dB below the fundamental will not be detectable on the oscilloscope.

The problem of ambient noise is more serious. Most detecting mechanisms are sensitive to the equivalent sound pressure. If the detecting mechanism has a uniform sensitivity over a frequency range Δf and is exposed to a pure tone plus a noise of bandwith Δf, the equivalent level of the noise at the sensor will be its spectrum level $+10 \log \Delta f$. If Δf is 10 Hz, the equivalent pressure level of the noise will be 10 dB higher than the spectrum level, or if Δf is 100 Hz, the equivalent pressure will be 20 dB higher than the spectrum level.

Since, in this experiment, the spectrum level of the ambient noise increases considerably as the frequency decreases, the author is probably correct in suggesting that the detection levels below 500 Hz may be determined by the ambient noise.

Where the yellowfin is compared with *Haemulon sciurus*, the measured thresholds for yellowfin below 500 Hz are probably seriously influenced by ambient noise while the thresholds for *Haemulon* measured by Tavolga below 100 Hz may be seriously influenced by harmonics from the projector.

I think people who are sponsoring research in these areas are going to need to provide the support necessary to build tanks in which the ambient sound level is low, and provide equipment which will make it possible to really examine the exciting signals to be certain that they're really pure tone signals. It takes something better than just an oscilloscope to do this.

It would be interesting to determine the S/N ratio necessary for detection by animals such as fish. The human ear can detect a pure tone in noise when the pure tone is about 10–12 dB below the equivalent noise level. The sensing system of the fish may, however, be less sophisticated than the human sensing system.

MR. FITZGERALD: Dr. Albers has left me very little to say. I would say the same things he has said perhaps with a little expansion. I think the time has come where the field of bio-acoustics should recognize that you're wasting your time trying to make noise measurements in tanks. It's a discouraging thing to me to see people who are supposed to be used to the ocean, not using the ocean to make their measurements in. Most of your problems would disappear if you went into the bays and got a reasonable depth of water – 30 ft of water will do – and get rid of these side walls that are confusing things.

I have a second point on Mr. Iversen's paper with respect to his apparatus. The Clevite is a very poor standard receiving hydrophone. You'd be better off to use one of the Navy standards if you can get them that are flat over a wider frequency range.

I don't think these are thresholds at all. You are measuring a signal detection against a noise background, and the noise background you pick is pretty confusing. It would be much better to work in the open water and get detection thresholds against Gaussian noise that you can control and immerse the fish in. You could then keep reducing the noise source until you reached the point where the limiting detection was the self-noise of the fish itself.

This self-noise, of course, is what you're trying to find and what you're trying to get his own detection threshold or recognition differential measured against.

In a tank, the fish, of course, has to swim, and he's generating flow noise in the vicinity of his own receiving apparatus. This builds up to a level that may be the controlling factor, and could account for the differences from one measurement to another.

DR. FISH: I'm very much in favor of Mr. Fitzgerald's idea that it's much better to eliminate side walls by working at sea, but I wonder how Mr. Fitzgerald is going to eliminate contamination from other creatures that might be making sounds at the same time in the field?

MR. FITZGERALD: They shouldn't disturb your conditioned response as long as they aren't a broad band noise and as long as the level is low.

DR. TAVOLGA: I think what Mr. Iversen has are true thresholds. His lowest thresholds were at least 10 dB above the noise level, and I believe that the signal-to-noise ratio for fish signal detection is considerably lower than that.

Secondly, another reason I have for being confident in his thresholds is that we've gotten that U-shaped audiogram curve with other species where the noise level was not U-shaped. I'm reasonably confident about these thresholds, and they're high enough above the background noise to look good.

DR. VAN BERGEIJK: I'd like to comment on the threshold values, which are a bit on the high side to be considered pressure thresholds, because they're at levels of about 20 dB above a microbar. From 100 to a few hundred cycles, you can get displacement amplitudes that are high enough to directly excite sensory cells, of, for instance, the lateralis system. So it is right in that never-never land where it might be one or the other. They are not really high enough to say this is displacement, and they are not low enough to say it must be pressure wave reception.

The sensory cells in the inner ear are very definitely situated in such a way that they might be affected by displacement emanating from the swimbladder in response to a pressure wave.

I don't think the shape of the swimbladder is terribly important as far as the pressure reception of the fish is concerned. As long as there's an air bubble that will obey the gas laws, and all air bubbles do, there will be in fact a transformation of pressure into displacement. No matter what odd shape it has, it will be the case that this air bubble will change volume, and therefore act as a zero moment source, so the shape doesn't really matter very much.

DR. SUCKLING: As one who has been out on tuna boats, and watched the men catch tuna, and worked with them in tanks, it's a remarkable thing to have done any research on the hearing of tuna at all. I think for a project in research on fish hearing, this is just amazing work.

5272 June, 1967 SA 3

Journal of the
SANITARY ENGINEERING DIVISION
Proceedings of the American Society of Civil Engineers

DENSITY FLOW REGIME OF FRANKLIN D. ROOSEVELT LAKE

By Robert T. Jaske,[1] and George R. Snyder,[2]

INTRODUCTION

As consequence of the needs of the Bureau of Commercial Fisheries (BCF) and the U.S. Atomic Energy Commission (AEC) for better understanding of the thermal regime of Lake Roosevelt, and some lack of clarity regarding the accounting for cool water masses during the 1963 operation of the Columbia River Cooling Program undertaken annually by the Hanford Operation, a detailed study of the temperature and density currents was carried out during 1964. Additional confirming temperature data were also taken in 1965.

Considerable emphasis has been placed on the thermal regime of Lake Roosevelt as it contributes to the thermal conditions expected after completion of the United States-Canadian Treaty Projects. Investigators have reported in internal documents[3,4,5] the trend for reservoirs to distort both the extent and timing of the natural, annual thermal cycle. Recognizing that such structures were planned and constructed before serious study of thermal effects was integrated with project planning, some agencies now seek not only to

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Note.—Discussion open until November 1, 1967. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 93, No. SA3, June, 1967. Manuscript was submitted for review for possible publication on July 27, 1966.

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[3] Churchill, Milo A., "Control of Temperature through Streamflow Regulation," presented at the U. S. Public Health Service Symposium on Streamflow Regulation for Quality Control, Apr. 3-5, 1963.

[4] Churchill, Milo A., "Effects of Density Currents in Reservoirs on Water Quality," Journal of Water and Sewage Works, Nov. 30, 1965.

[5] Ward, J. C., "Annual Variation of Stream Water Temperature," Journal of the Sanitary Engineering Division, ASCE, Vol. 89, No. SA6, Proc. Paper 3710, Dec., 1963.

improve the understanding of these effects, but to capitalize on the advantages where practicable. The programs of the BCF and the AEC fall in this category.

EXPERIMENTAL PROCEDURE

During the early reservoir studies supporting the annual Cooling Program, thermocouples read with a standard decade box and ice baths were used. This cumbersome array was supplanted in 1963 by a Wallac RTD unit having case compensation and a probe 110 long. Data obtained with this instrument were precise to 0.1°C. Previous experience had shown the necessity to measure temperature accurately to find thermal evidence of shear gradients with some confidence. Despite its accuracy, the Wallac instrument proved difficult to use because of cord weight and the length of time required to achieve equilibrium at each depth. A review of available equipment suggested the following apparatus which was optimized for aircraft transport.

The actual instrument consisted fo four component parts; i.e., power converter, temperature measurement system, thermister and cable, and recorder. A standard dc-ac inverter utilized the aircraft power supply to run the chart recorder.

The temperature measurement system was a portable, battery regulated, three resistance bridge unit containing the separate bridge circuits. A switch provided selection of three temperature ranges (0 to 10° C, 10 to 20° C, and 20 to 30° C). All resistance bridges were factory calibrated for the sensor and cable, and were factory installed. The bridge residual effect ranges from 0.002 to 0.05% of full scale output voltage (output voltage range is zero to 0.01 mv).

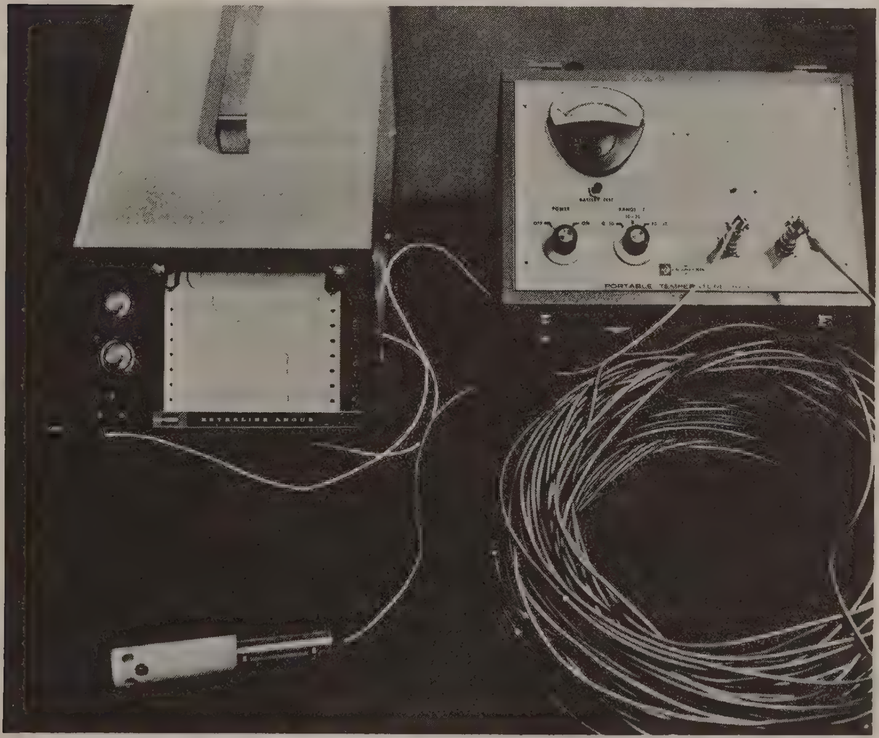
Included in the water temperature measuring system is a platinum resistance immersion sensor and 400 ft of cable. Time constant for the sensor is 2.5 sec and the accuracy is ± 0.05° C. The four-wire cable is marked with a color code and numbers to facilitate rapid depth indentification of the sensor.

A 6-in. series S recorder with a servopotentiometer measuring element was used to record the temperature. Response of this instrument is 90% full scale in 1/8 sec, accuracy 0.5% of full scale, and sensitivity 1/8% of full scale. Depth was recorded on the chart at each 0.2° C temperature change throughout the depth of the profile.

Because of the distances involved and the desire to minimize data bias because of time variation, aircraft appeared to be the proper choice for all data surveys. The lake was divided into ten segments of ten nautical miles in length which appeared, on the basis of previous experience, to give proper coverage.

Commencing on April 15, 1964, flights contracted by Fish Passage Research were made weekly through October 19, 1964, taking profiles at the ten stations. This program was repeated between May 1 and November 1, 1965. At each letdown, the equipment was calibrated against a certified thermometer, and recording began until bottom was manually indicated. A complete data run took less than 5 hr. The entire operation, based at Seattle, Wash., took less than 10 hr per trip. Some weather interference was encountered; one trip was cancelled because of bad weather in August, 1965; and wind caused drift problems on some days. However, the recording equipment performed satisfactorily and no runs were aborted for this reason. The aircraft

FIG. 1.—SUPPORTING AIRCRAFT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PORTABLE TEMPERATURE

FIG. 2.—APPARATUS ON BENCH

and experimental apparatus are illustrated in Fig. 1 and 2. The data converted to thermal maps are included herein.

As the data were collected, it became apparent that confirmation was required for the observations that the existance of a three slope temperature profile defined density current position. By means of a boat, a set of simultaneous temperature and current measurements was made on September 3 and 4, 1965, at the same stations used for the standard program. The Rosemount temperature apparatus was also used at this time. Current measurements were made with Savonius rotor speed sensors and current direction indicators manufactured by the Hydroproducts Division of OEC. The ordinary useful speed range is 0.05 to 7 knots, although with patience, lower readings of lesser accuracy can be made down to 0.02 knots. The accuracy is ± 3% within the normal scale range. The current direction sensor is normally correct to 5°. The survey boat was securely anchored at each site prior to profile measurement. The preliminary nature of the study precluded a more stable platform, but the results obtained appear adequate to demonstrate the principle involved.

RESULTS OF STUDY

For several years, interest has centered on the development of improved heat budgets and better modeling of the density current regime in reservoirs. The alteration of the normal temperature distribution has been described by M. A. Churchill[3,4] and J. C. Ward.[5] Commencing in the early 1950's, these and other investigators began a search for an appropriate model of density current regime. In 1958, C. S. Yih[6] reported that for large densimetric Froude numbers there was no tendency for flow separation. As the Froude number decreases below a critical value of $1/\pi$, the conditions of the analysis predict that the entire depth of fluid cannot be in motion toward the outlet and an internal current with a thickness less than the total depth results.

In 1959, using laboratory troughs, W. R. Debler[7] developed a correlation for the Yih prediction that the dividing streamline in a stratified reservoir could be modeled as a function of the densimetric Froude number, F. Fig. 3 illustrates this relationship and is reproduced from Debler's original paper.[7] The reader is encouraged to review the original reference for development of the mathematical analysis.

A study of this work reveals that three rather unnatural conditions were adopted to simplify the laboratory work, as follows:

1. The tests were commenced from a state of static equilibrium at R essentially zero;
2. the flow outlet was located at the very bottom of the test trough; and
3. the trough dimensions were chosen to minimize edge effects.

While these conditions have application to a number of reservoirs, a study of many western reservoirs indicates that one or more of these conditions usually does not exist. In Lake Roosevelt, none of the conditions exists.

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[6] Yih, C. S., "On the flow of a Stratified Fluid," Proceedings, 3rd International Congress of Applied Mechanics, 1958.

[7] Debler, W. R., "Stratified Flow into a Line Sink," Journal of the Engineering Mechanics Division, ASCE, Vol. 85, No. EM3, Proc. Paper 2093, July, 1959.

N. Duncan, D. R. F. Harleman, and R. A. Elder[8] have reported on the application of this method to Fontana Reservoir in support of other project activity. While good correlation of the density current boundary was obtained, complications were encountered in explaining the action of the lower boundary since this dam had an outlet some distance above the bottom.

During this period, commencing in 1958, the Richland Operations Office of the AEC, through the General Electric Company—then sole operating contractor at Hanford—arranged to alter the delivery of water from Grand Coulee Dam to favor a cooler water regime both above and below the plant reach. Efforts to account for the cool water inventory were never fully successful. As additional dams were completed, the flow regime was further confused, although the original incentives still remain of interest to both the AEC and the Fish and Wildlife Service. This work is continuing and a promising, dynamic river model programmed for the UNIVAC 1107 in Fortran IV language is currently in routine operation at Hanford.[9] The necessity to account for heat balance in the special releases, and the inability to do so using existing theory, lent special emphasis to improved understanding of density currents in Lake Roosevelt.

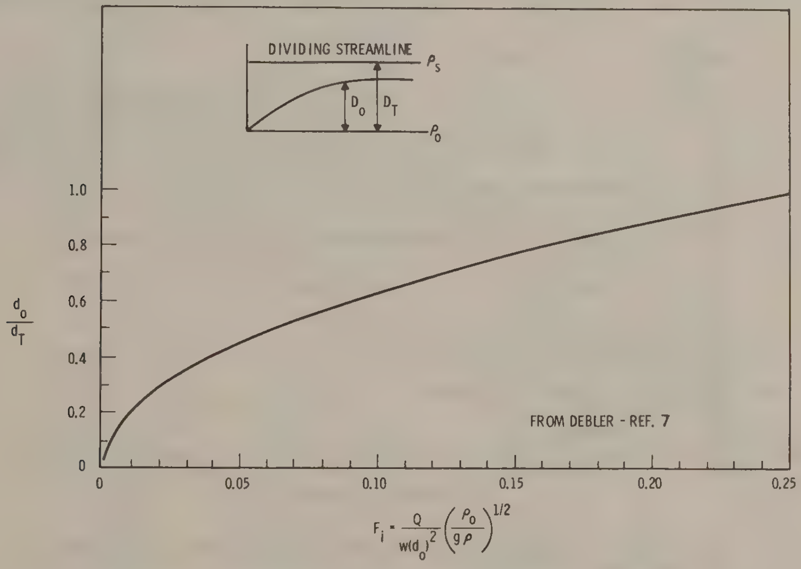

FIG. 3.—CORRELATION OF DEPTH OF DIVIDING STREAMLINE

Accepted theory, developed on the concept of static equilibrium (Fig. 4), would lead the investigator to conclude that density currents should develop a flow through Lake Roosevelt. The cooling program initiated by General Electric was operated on the assumption that the warmer, stratified upper layers could be trapped by reducing spill to zero and discharging all cool water through the penstocks at the 1,030-= ft elevation. If a flow jet could be established, these upper layers would cool to the atmosphere and not contribute to the downstream thermal balance.

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[8] Duncan, N., Harleman, D. R. F., Elder, R. A., "Internal Density Currents Created by Withdrawal from a Stratified Reservoir," Tennessee Valley Authority and U. S. Corps of Engineers, Norris, Tenn., Feb., 1962.

[9] Jaske, R. T., "An Evaluation of the Use of Selective Discharges from Lake Roosevelt to Cool the Columbia River," BNWL-208, (USAEC-TID), Mar. 16, 1966.

Data collected in 1963, however, indicated that the expected density pattern was being interfered with by the dynamic flow conditions through the reservoir. The net effect was to produce hold-up of cool water and an unexpected flow of warmer water after the expected time. Replenishment of water from the north produced the appearance of displacement flow rather than density flow. However, computation of the density interface using the Yih-Debler correlation indicated the presence of a dividing streamline. Clearly some additional effects were operating to alter the expected pattern.

Further study of the available temperature data, including some available from Davidson of Grant County Public Utility District No. 2, showed a frequent pattern illustrated by the profiles shown in Fig. 6. These profiles suggest that the upper and lower dividing streamline can be located by the changes in slope of the temperature profile. For preliminary survey work, this method has the obvious advantage of using more readily obtained temperature readings as opposed to the cumbersome job of handling current metering equipment. This effect was also noted by Duncan, Harleman, and Elder[8], and forms the basis for the prediction of ocean thermal structure forecasting by the U.S. Navy.[10]

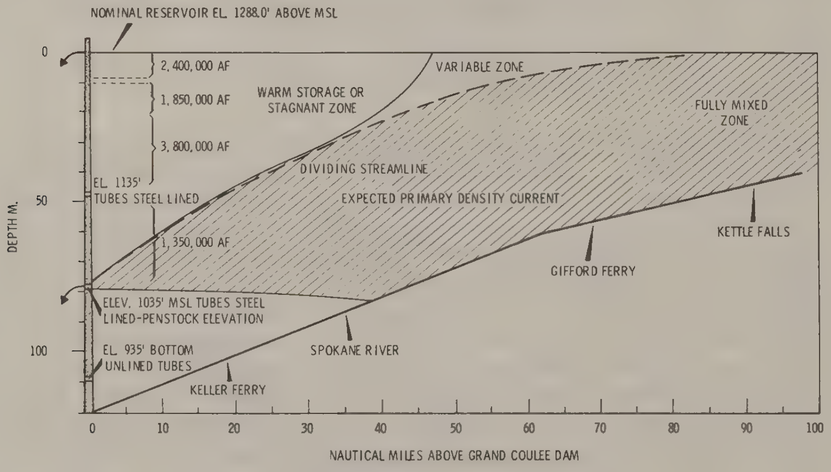
NOMINAL RESERVOIR EL. 1288.0' ABOVE MSL
0
2,400,000 AF
1,850,000 AF
3,800,000 AF
WARM STORAGE OR STAGNANT ZONE
VARIABLE ZONE
FULLY MIXED ZONE
DIVIDING STREAMLINE
EL. 1135' TUBES STEEL LINED
EXPECTED PRIMARY DENSITY CURRENT
50
DEPTH M.
1,350,000 AF
KETTLE FALLS
GIFFORD FERRY
ELEV. 1035' MSL TUBES STEEL LINED-PENSTOCK ELEVATION
100
EL. 935' BOTTOM UNLINED TUBES
SPOKANE RIVER
KELLER FERRY
0
10
20
30
40
50
60
70
80
90
100
NAUTICAL MILES ABOVE GRAND COULEE DAM

FIG. 4.—EXPECTED FLOW CONDITIONS USED FOR PLANNING BEFORE 1963

On the basis of this speculation, the special set of data using both current meters and temperature sensors was taken by boat on September 3 and 4, 1964. Figs. 5 and 6 also illustrate the results of this survey and the partial confirmation of the concept suggested previously herein. The actual current distribution cannot be ascertained definitely, but the patterns suggest that the flow consists of undulating flat sheets which rise and fall in response to the dynamic equilibrium. The distribution of current appears to favor the lower level, perhaps following a distribution similar to a specific energy diagram.

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[10] "Ocean Thermal Structure Forecasting," Report SP-105, Antisubmarine Warfare, Environmental Prediction Services, U. S. Navy.

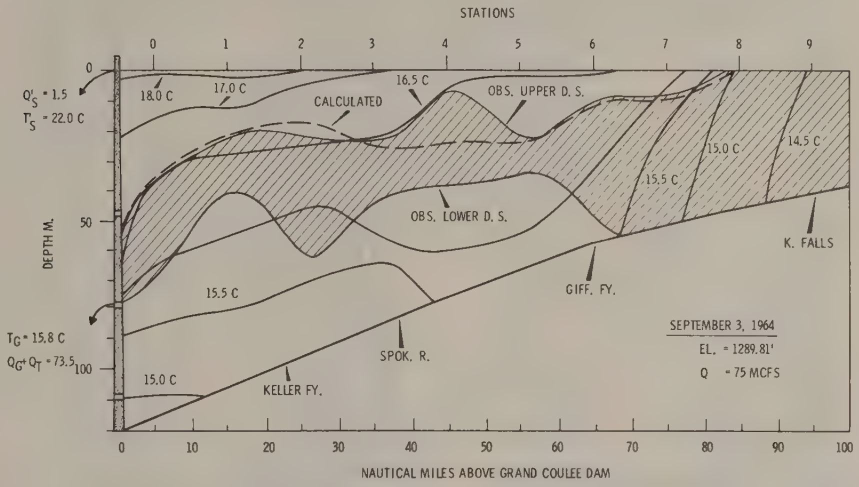

FIG. 5.—FLOW JET PATTERN FROM MEASURED CURRENT DATA

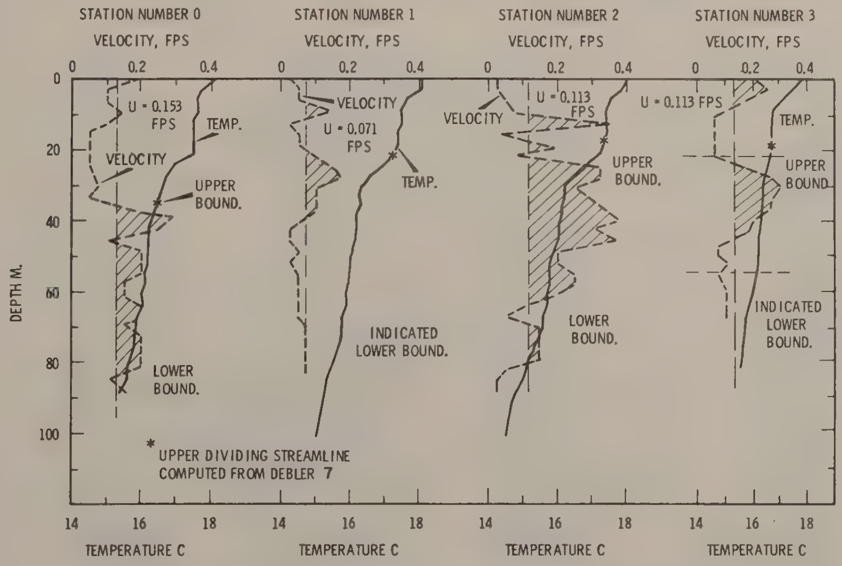

FIG. 6.—VELOCITY AND TEMPERATURE VERSUS DEPTH: SEPTEMBER 3, 1964

Additional research by Battelle-Northwest to fully explore this and other current distribution related to the regulated use of Lake Roosevelt is in process of review by the Department of Interior.

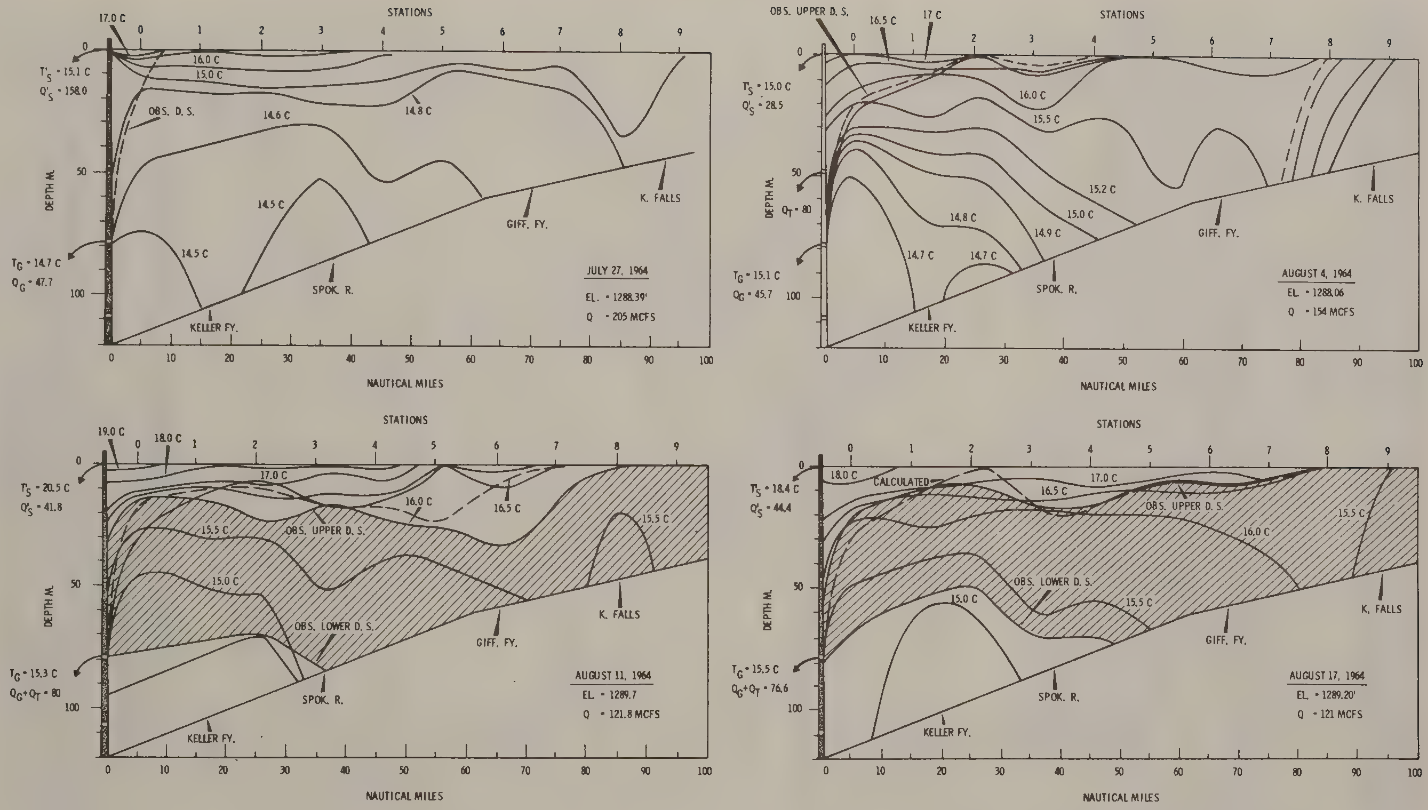

FIG. 7.—PROGRESSIVE DEVELOPMENT OF STRATIFIED REGIME: LAKE ROOSEVELT, JULY-AUGUST, 1964

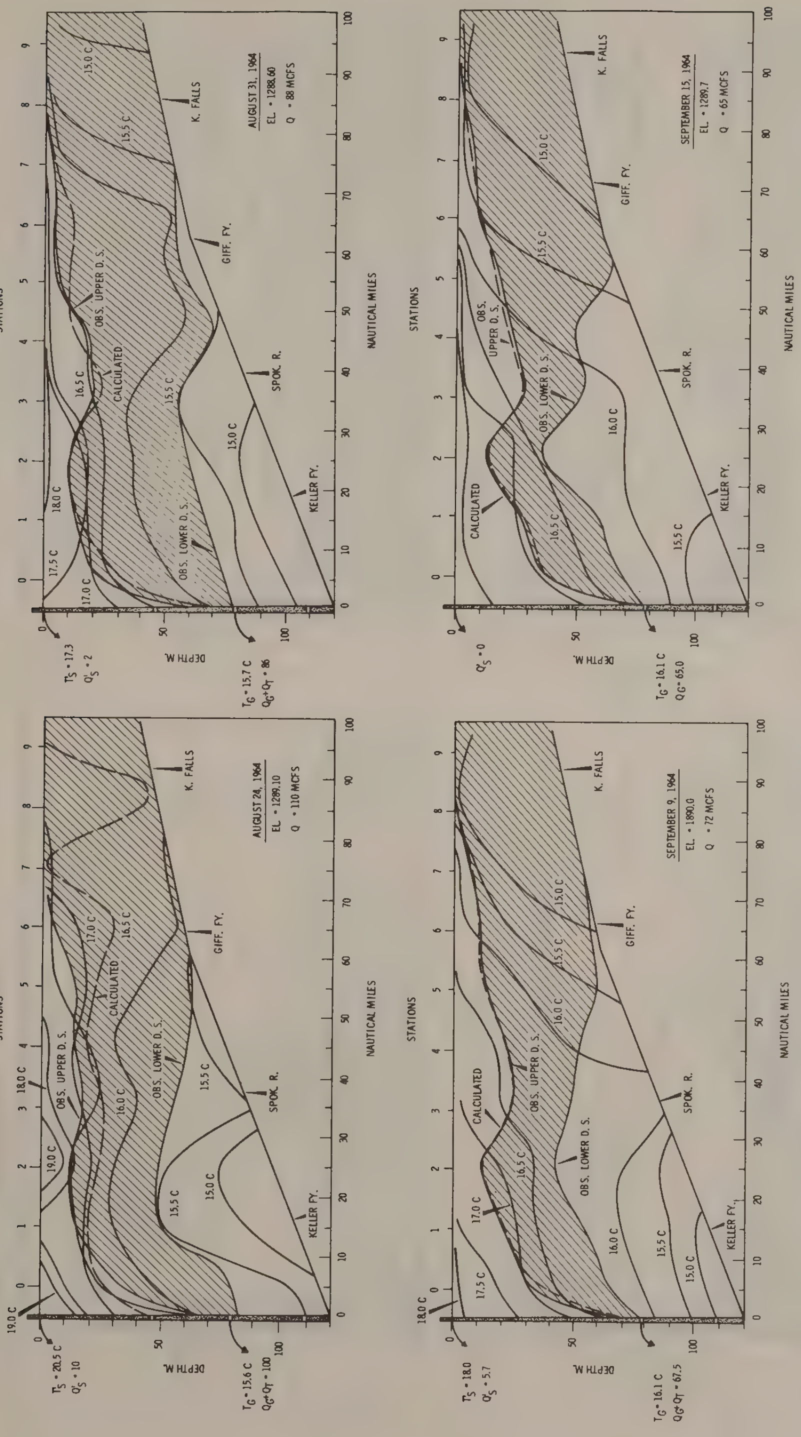

FIG. 8.—PROGRESSIVE DEVELOPMENT OF STRATIFIED REGIME: LAKE ROOSEVELT, AUGUST-SEPTEMBER, 1964

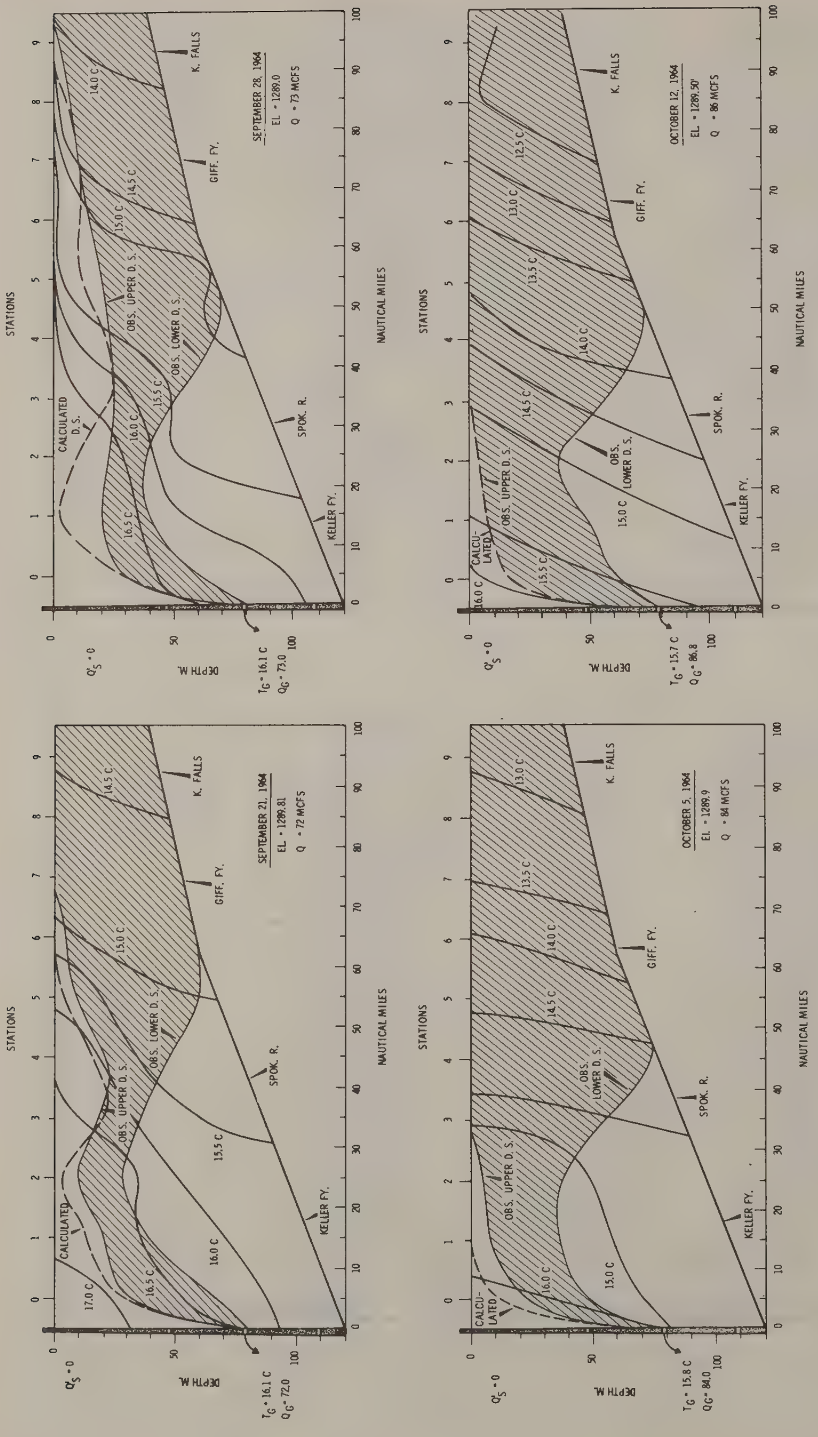

FIG. 9.—RECESSION OF STRATIFIED REGIME AND ON-SET OF DISPLACEMENT FILLING FROM NORTH: LAKE ROOSEVELT, SEPTEMBER-OCTOBER, 1964

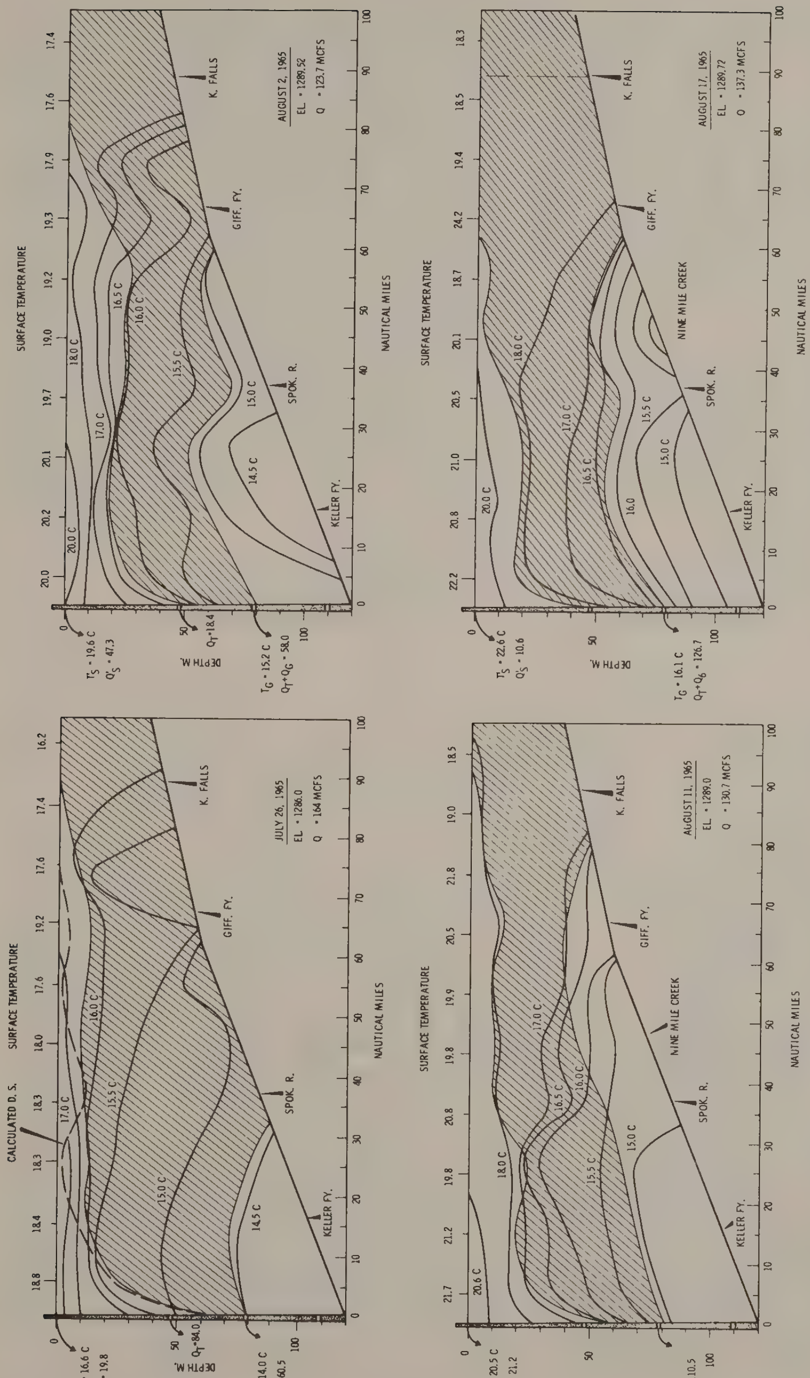

FIG. 10.—PROGRESSIVE DEVELOPMENT OF STRATIFIED REGIME: LAKE ROOSEVELT, JULY-AUGUST, 1965

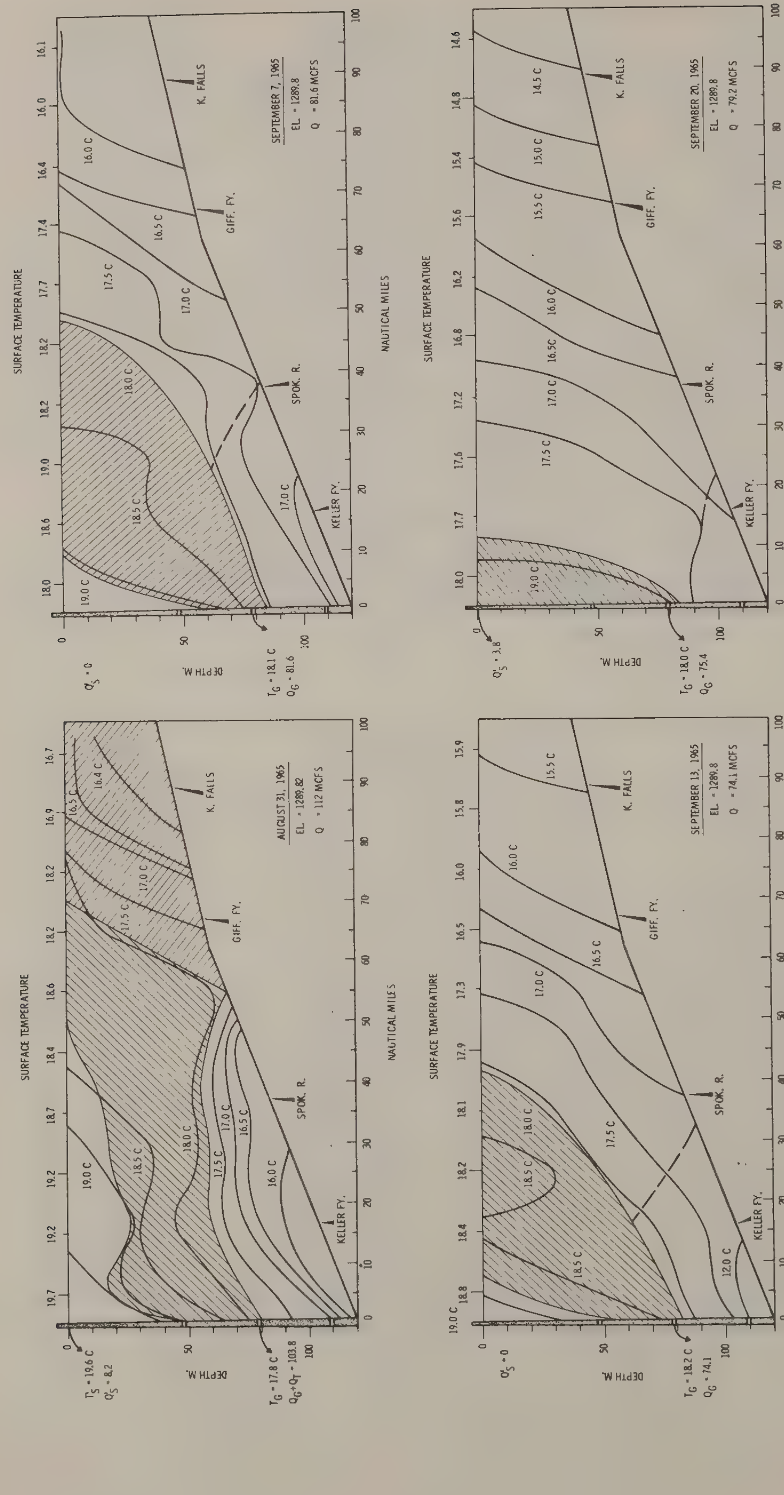

FIG. 11.—RECESSION OF STRATIFIED REGIME AND ON-SET OF DISPLACEMENT FILLING: LAKE ROOSEVELT, AUGUST-SEPTEMBER, 1965

However, the results of the preliminary boat run were sufficiently novel for the writers to call attention to the existance of the actual flow conditions within the reservoir. Field data show that these conditions differ from the Yih-Debler concept in several important respects.

The flow and temperature regime for the significant months of 1964 and 1965 are given in Figs. 7 through 11. These figures show the development of the stratified condition commencing in late July, the development of the current jet, and the incoming displacement flow which fails to enter the jet at any time during the cycle. Where appropriate, the boundaries of the current jet as determined by the change in temperature profile methods are delineated. The computed locations of the upper dividing streamline as derived from the Debler correlation are also superimposed on the 1964 data.

The existance of a flow jet bottom at some elevation above the outlet location is being studied and attempts to improve the jet flow model described by R. R. Long in 1962[11] are underway. Additional energy terms that cause resultant isotherms to be tilted upward may explain both the diving phenomenon at the outlet and the displacement type replenishment from the north. The inlet trash gates, which consist of vertical, elongated cages, may also contribute to the unexpected current distribution.

CONCLUSIONS

As a result of this program, it appears that the following conclusions are appropriate:

1. The correlation of the upper boundary predicted by Yih and demonstrated by Debler in trough experiments is sufficiently correct to be applied to engineering analysis in the design of outlet works. This applies to rapidly flowing reservoirs as well as relatively quiet systems.
2. The bottom of the flow path created in a reservoir by discharge from a point below the surface does not necessarily remain below the elevation of the point of discharge. Rather, due to the conditions imposed by dynamic forces, the flow path separation layer or shear zone follows dynamic influences similar to the upper boundary and rises, as necessary, to maintain dynamic equilibrium. This conclusion is, of course, dependent on further confirmation of the preliminary information on which it was based.
3. In the regime studies, the term "stagnant zone" is purely relative. At no time were currents less than 0.05 fps measured at any elevation. Current speed distribution, both above and below the flow path, was of the same order of magnitude. Current speeds in the flow jet were from 3 to 5 times those in the so-called stagnant zones.
4. Operational concepts which envision use of the storage capacity of Lake Roosevelt to alter thermal conditions either expected from storage upstream in Canadian Treaty Reservoirs or presently existing must be designed or operated to cope with the actual flow regime discovered. It is quite apparent that the reservoir does fill by displacement from the north and does not develop a true continuous density current regime of any significance. This does not preclude operational plans which would save cold water by curtailment of the annual spring drawdown for flood control if sufficient upstream storage

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[11] Long, R. R., "Velocity Concentrations in Stratified Fluids," Journal of the Hydraulics Division, ASCE, Vol 88, No HY1, Proc. Paper 3038, Jan., 1962.

volume can be found to supplant the volume currently drained each spring. Retention of this cold water now discharged for flood control would restore some of the seasonal imbalance in Columbia River temperatures currently existing.

5. Downstream activities sensitive to dissolved ion and turbidity content are affected by reservoir flow path which by-pass cooler, chemically rich Spokane River inflows. Temporary holdup of this inflow, bearing a large percentage of the dissolved material sensitive to activation by downstream nuclear reactor processes, may account for the annual diminution of ^{32}P and ^{76}As content normally observed below the Hanford plant.

ACKNOWLEDGMENTS

The writers acknowledge the cooperation of Raymond Seeley, Power Superintendent, and his staff at Grand Coulee Dam for their cooperation in reading temperature records, operating facilities, and other supporting activities carried out to assist this study.

Acknowledgment is extended to the Bureau of Commercial Fisheries for the use of original data, photographs, and the 1964-1965 surveys. The information was gathered by the Fish-Passage Research Program based at Seattle, Wash., under the direction of G. B. Collins.

Additional acknowledgment is also given to the Richland Operations Office of the United States Atomic Energy Commission, for whom the annual Columbia River Cooling Program has been carried out, and to the General Electric Company, prime contractor at Hanford at the time these studies were initiated.

APPENDIX.—NOTATION

The use of metric units in combination with English units is based on chemical industry technology and the desire of the writers to make a gradual transition to the metric system while retaining reader impressions of traditional volume units. The following symbols are used in this paper:

F = densimetric Froude number, used as an internal concept with the observed jet bottom as the lower boundary for the computation of thermal gradient and flow flux per unit width;
Q = river or reservoir flow in thousands of cubic feet per second;
Q_g = discharge through turbin penstocks, in thousands of cubic feet per second;
Q_t = discharge through by-pass tubes, in thousands of cubic feet per second;
Q'_s = discharge over spillway, in thousands of cubic feet per second;
Q_s = spill flow, defined at $(Q_t + Q'_s)$, in thousands of cubic feet per second;
T_g = temperature of turbine discharge, in degrees centigrade;
T_t = temperature of tube discharge, ordinarily taken as equal to T_g, degree C; and
T'_s = computed temperature of spill from over-all heat balance, in degrees centigrade.

5272 DENSITY FLOW REGIME OF ROOSEVELT LAKE

KEY WORDS: Canadian Treaty; Columbia River; density current; flow regime Lake Roosevelt; reservoir; sanitary engineering; stratification; thermal regime; water flow

ABSTRACT: The thermal regime of Lake Roosevelt for the summers of 1964 and 1965, when compared with Yih and the Laboratory studies of Debler, shows good agreement regarding the position of the interfacial layer between the upper relatively stagnant zone and the region of primary flow transport. Further study of the temperature data and confirmation by a limited amount of current measurement shows the location of a second, lower interface roughly conforming to the upper boundary. During the season when stratification occurs, the resulting jet flow travels in a flat, undulating fashion, at times rising above the level of the discharge. Existing theory appears inadequate to fully predict this behavior, although an empirical relationship can be derived to perform engineering analysis. The study confirms the necessity to consider density currents in the management of special releases and in thermal and chemical material balances. Furthermore, the dynamic conditions within the reservoir distort the resulting flow jets to the extent that cooler masses can be by-passed. Another result is the blocking of the formation of "normal" current jets, and, as a consequence, Lake Roosevelt fills with cool water by displacement from the north without any significant horizontal redistribution.

REFERENCE: Jaske, Robert T., and Snyder, George R., "Density Flow Regime of Franklin D. Roosevelt Lake," Journal of the Sanitary Engineering Division, ASCE, Vol. 93, No. SA3, Proc. Paper 5272, June, 1967, pp. 15-28.

Size Selection and Retainment of Silver and Red Hake in Nylon Codends of Trawl Nets

ALBERT C. JENSEN[1] AND RICHARD C. HENNEMUTH[2]

Abstract

Three experiments were conducted to determine the size-selectivity and relative catching efficiency of 52-, 71-, and 73-mm mesh, nylon codends for silver and red hake. A research vessel was used in the first experiment to estimate retainment in the 52- and 73-mm codends, and to compare results with covered and uncovered codends. Commercial fishing vessels were used for two experiments to estimate selectivity of a 71-mm mesh in actual commercial operations.

The covered codend retained proportionately more of the smaller fish than did the uncovered codends. The alternate tows with uncovered codends provided some evidence of an increased catch with the larger meshes. However, the 71–73-mm codends release a large proportion (up to 50%) of fish in the 25–35-cm length group, which contains the bulk of fish available to commercial trawl nets. The release of fish less than 25 cm in length is not much greater in the 71-mm codends than in the 52-mm codends. The conclusion is that the 52-mm codends are near the optimal size for these species.

These experiments were conducted by personnel of the Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts, during 1964 to determine the size-selectivity and relative catching efficiency of 52-, 71-, and 73-mm mesh (2.0, 2.8, and 2.9 inches)[3], nylon codends for silver hake, *Merluccius bilinearis*, and red hake, *Urophycis chuss*. This information was needed to assess the effect of the larger mesh on commercial catches.

The *Delaware*, a research vessel of the Bureau, was used for the first experiment, in which personnel of the Exploratory Fishing and Gear Research Base at Gloucester, Massachusetts, cooperated. The objectives were to estimate selectivity of the 52- and 73-mm mesh codends, and to compare estimates obtained with covered and uncovered codends. Commercial fishing vessels were used for the two subsequent experiments to estimate selectivity of a 71-mm mesh nylon codend in actual commercial operations.

A typical vessel in the Gloucester, Mass., fleet was chosen for the first of the commercial trials. This fleet currently uses a 50-mm (2.0-inches) mesh, nylon codend and lands silver hake almost exclusively for human food. Two typical vessels of the Pt. Judith, Rhode Island, fleet were used in the second commercial trial. This fleet lands silver hake and red hake primarily for industrial purposes (i.e., meal and animal food), and currently uses a small mesh (33 mm, 1.3 inches) nylon liner in the codend.

Fishing areas providing a high proportion of silver hake in catches were chosen, because this species was of primary interest. Red hake were caught incidentally during the *Delaware* experiment, and a 1-day experiment at Pt. Judith was conducted to provide additional data. Relatively small amounts of other species were caught, but are not considered herein.

This paper presents the procedures and results of the three experiments, and considers the probable effects on commercial catches of the use of the larger mesh.

Experimental Procedure and Methods of Analysis

Delaware experiment

The experiment was conducted from 29 June through 6 August in the near-shore area of the Gulf of Maine. The trawl net was similar in construction to that used by commercial fishermen, with 64-mm (2.5-inches) mesh of No. 54 thread, cotton equivalent nylon throughout the wings and body.

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[1] Institute of Marine Science, University of Miami, Miami, Florida, USA.

[2] US Bureau of Commercial Fisheries, Woods Hole, Massachusetts, USA.

[3] Stretch measure of wet mesh, after use, using an ICES gauge (Westhoff, *et al.*, 1962) at 4.4 kg of pressure.

Two series of 30 tows were completed. Within each series, five successive tows on both the port and starboard sides of the vessel were to be made with each of three types of codends; a 52-mm mesh covered with a 31-mm mesh (Clark, 1963*a* for method of attachment), a 52-mm mesh, and a 73-mm mesh, both without covers. The codends and vessel sides were used in random order; the tows averaged about three-quarters of an hour.

As with most experiments at sea, operational exigencies modified the procedure. Two serious tear-ups caused more tows to be made on the starboard side than the port side in the second series. The resulting array of tows was as follows:

Codend mesh (mm):	52/31[a]		52		73		Total
Side:	Port	Stbd.	Port	Stbd.	Port	Stbd.	
Series 1	5	5	5	5	5	5	30
Series 2	2	8	5	5	4	6	30
Total	7	13	10	10	9	11	60

[a] 52 mm covered with 31 mm.

All fish from a representative, 2-bu[4] sample from each tow were weighed, measured, and counted. In occasional catches of less than 2 bu, all fish were measured and counted. The total number of bushels in each tow also was counted. The total number and total weight of silver hake and red hake in the tow were estimated by multiplying the average number and weight of fish per sample bushel by the total number of bushels. The length-frequencies of the fish in the sample were used to estimate total numbers caught per 3-cm length interval.

Retention curves for the 52- and 73-mm mesh codends without covers were drawn by plotting for each 3-cm interval the ratios of the estimated numbers of fish retained in the larger mesh codend to that retained in the codend covered with the 31-mm mesh (including fish in the cover). The 31-mm mesh is fine enough to retain nearly all of the sizes of fish available to the trawl.

The selection curve for the covered 52-mm mesh codend was derived by estimating the ratios of the number retained in the cover to that retained in the codend and cover.

The average length at which 50% of the fish were retained was estimated from lines drawn by inspection through points of the retention ratios plotted on probability paper. The selection factor is the quotient of the 50% length divided by the mesh size.

Gloucester experiment

To make the results of this experiment meaningful in relation to the silver hake commercial fishery, it was important that the experiment be conducted during normal fishing operations. This was accomplished by placing a Bureau observer aboard a cooperating Gloucester vessel, the *Frances R.*, a wooden dragger of 57 gross tons, during two regular 1-day trips. The vessel used the experimental 71-mm mesh codend on the first day (30 September) and the standard 50-mm mesh codend on the second day (2 October). No changes were made in the net itself, and no covers were used. The vessel fished in an area about 12 miles south-southeast of Gloucester. Eight tows of 2 hr each were made with each codend.

The procedure for sampling the catch was the same as that followed aboard the *Delaware* except that 2-bu samples of silver hake only were measured and counted on all tows; the catches were all large, and almost 95% silver hake. The mean weight per fish in each sample was estimated by using a length-weight relation obtained from a special sample of fish. The captain's estimate of the weight of the total catch —usually a reliable estimate—was divided by the mean weight per fish to estimate the total number of fish in the catch. This procedure was necessary because it was impractical to count and measure the entire catch.

Pt. Judith experiment

Two typical commercial vessels, the *Nyanza* and *David D.*, wooden draggers of 39 and 27 gross tons, respectively, cooperated in this experiment. Observers from the Bureau accompanied both vessels on three, one-day trips, during which the vessels fished within 1 km of each other on commercial grounds.

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[4] 1 bushel=about 30 kg of fish.

On the first of the silver hake trips (19 October), one vessel used the experimental 71-mm mesh codend attached to the net normally used in fishing. The other used the standard codend, 127-mm nylon mesh lined with a 33-mm nylon mesh. On the second trip the vessels exchanged codends. In all, 21 tows of about 1 hr each were completed, of which 16 were sampled.

The red hake experiments were completed on a single subsequent day (22 October), during which one vessel used the large mesh codend and one the small mesh codend liner. Each vessel completed four tows of about one hour's duration.

The sampling and estimating procedures were the same as those outlined for the Gloucester experiment.

Results

Silver hake

The data on catch and selectivity for each experiment and type of codend are presented in Table 1 and Fig. 1–4. There are several aspects of particular interest.

TABLE 1. Catch and selectivity of silver hake for three experiments.

	Delaware			Gloucester		Pt. Judith	
Mesh size (mm):	31	52	73	50	71	33	71
Length int. mid-point	Numbers caught						
cm							
12	136	—	—	—	—	97	—
15	1,170	125	59	70	14	422	48
18	2,183	417	79	496	82	2,558	174
21	1,365	313	89	936	125	6,815	341
24	3,496	793	463	2,380	792	12,553	2,614
27	9,084	5,239	2,424	19,640	5,842	17,111	5,828
30	4,696	5,156	2,168	18,410	7,035	26,585	14,889
33	3,496	5,260	2,484	7,085	4,138	11,728	11,054
36	1,558	2,380	1,222	1,275	725	4,685	4,733
39	586	730	473	192	123	1,688	3,043
42	229	209	118	—	37	642	1,101
45	102	104	89	—	34	212	400
48	76	42	59	—	111	47	200
51	51	42	49	—	20	67	—
54	—	21	29	141	—	—	—
57	—	21	10	—	14	—	9
60	—	—	10	—	—	—	—
Total	28,228	20,852	9,825	50,625	19,092	85,210	44,434
Total weight:							
kg	4,472	4,254	1,975	7,713	3,176	20,417	10,662
lb.	9,856	9,376	4,352	17,000	7,000	45,000	23,500
No. tows	20	20	20	4	4	11	10
Hours towed	14.7	14.6	14.4	8.0	7.0	12.0	12.1
Weight per hour:							
kg	304	291	137	965	454	1,702	882
lb.	670	642	302	2,125	1,000	3,750	1,942
Ratio of weight per hour[a]	—	0.96	0.45	—	0.47	—	0.52
Selectivity:							
50% length (cm)	15.8	26.4	30.4	—	31.8	—	29.3
selection factor	3.2	5.08	4.16	—	4.27	—	4.13

[a] Ratio of catch of larger mesh to smallest mesh in each experiment.

The selection curve for the 52-mm mesh obtained from tows with the covered codend is quite different from that obtained from alternate tows without the cover (Fig. 1). Both the 50% length and the selection factor are lower for the former (15.8 and 3.2 vs. 26.4 and 5.08, respectively); the covered codend is retaining proportionately more of the smaller fish. Escapement may be reduced by a "masking" effect of the cover; small fish may also re-enter the codend when vessel speed is reduced during haul-back. Clark (1963*b*) also observed this effect in similar experiments with 80-mm codends.

There is a rather sharp size-selection in the uncovered 52-mm mesh; the 25–100% retention is within a length range of 5 cm, whereas the range is about 10 cm for the 73-mm mesh, which exhibits a more gradual retention curve.

Retention ratios greater than one were observed for the 52-mm mesh in the *Delaware* experiments and for the 71-mm mesh in the Pt. Judith experiments (Fig. 1, 3). In alternate tow experiments, the retention ratios are the resultant of two factors—escapement through the mesh and catch rate. Ratios greater than one imply the larger mesh is more efficient, providing both nets fished the same average population density. Even if relative efficiency is an important factor, it will be apparent in retention curves only when the increased catch more than compensates for escapement, i.e., generally towards the upper limb of the curve, and this may not obtain for the larger meshes over the observed size range of fish. Unfortunately, the data are not consistent enough to substantiate or estimate the implied increased efficiency.

Regardless of the underlying causes, the retention curves from alternate tows do portray, within limits of sampling error, the expected effect in commercial application. This may not be so for the covered codend results.

Another important result is the observed effects on total catch rate. The 71- and 73-mm mesh codends caused a loss of about 50% by weight compared to the 31- or 33-mm meshes. In contrast, the *Delaware* experiment indicated a loss of less than 5% with the 52-mm mesh (Table 1).

The reduction of catch is also evident in comparisons of catches made by the *Frances R.* using the 71-mm codend with those of three other vessels of similar size and horsepower fishing nearby with 50-mm codends:

Vessel	Hours towed	Catch	
		kg	*lb.*
Frances R.	1.7	636	1,400
Little Flower	1.6	909	2,000
Frances R.	2.0	1,137	2,500
Sebastiana C.	2.0	1,362	3,000
Frances R.	7.0	3,181	7,000
Barbara C.	7.0	6,820	15,000

The difference in catch rate is important in application, but, of course, depends on the length-frequency of the available population. This subject will be taken up again in the subsequent section on commercial fishery application.

The retention curves obtained on the 2 days at Pt. Judith are very nearly coincident and the data were pooled to provide a single curve (Fig. 3).

The overall uniformity of results of the several independent sets of data for the 71- and 73-mm mesh codends (at least for fish up to 36 cm) provides a fair measure of confidence in the results (Fig. 4). The retention ratios of the 71-mm mesh obtained in the Gloucester experiment cannot be directly compared to the others because a larger base mesh was used (50 mm vs. 31 and 33 mm); therefore, the retention ratios in Fig. 4 have been adjusted by the retention ratios of the 52-mm mesh estimated from the *Delaware* experiment to make them comparable to a 31-mm base net. The remaining small differences in mesh size between experiments (31 vs. 33 mm, 50 vs. 52 mm, 71 vs. 73 mm) are of little consequence in the final results. Thus, for a codend of nylon mesh averaging 72 mm, the 50% length and selection factor may be taken as the average of those in Table 1, 29.8 cm and 4.2, respectively.

Small numbers of fish larger than 39 cm in the catches preclude firm estimates of retention and relative catch of fish for those sizes. Note also the small catches in the *Delaware* experiment compared to the commercial experiments. This might affect the retention characteristics, although it is not apparent that it has done so.

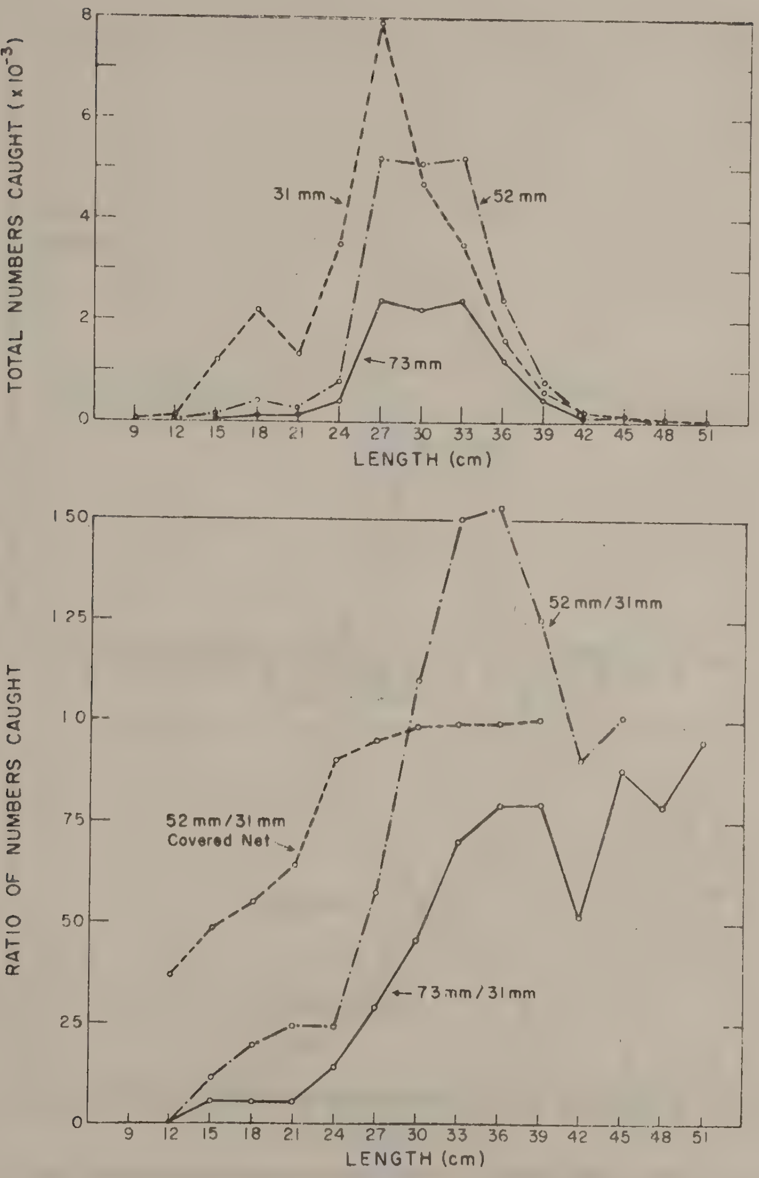

Fig. 1. Retention of silver hake in 52-mm and 73-mm nylon codends, *Delaware.*

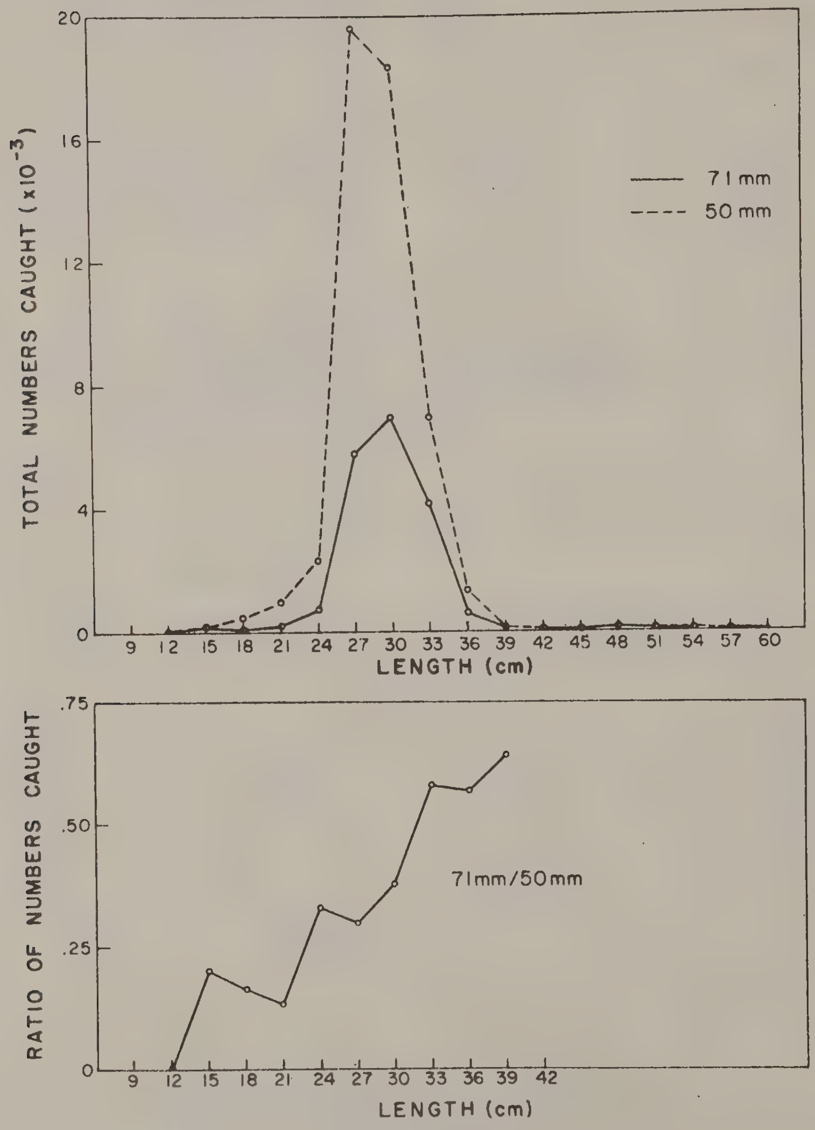

Fig. 2. Retention of silver hake in 50-mm and 71-mm nylon codends, Gloucester.

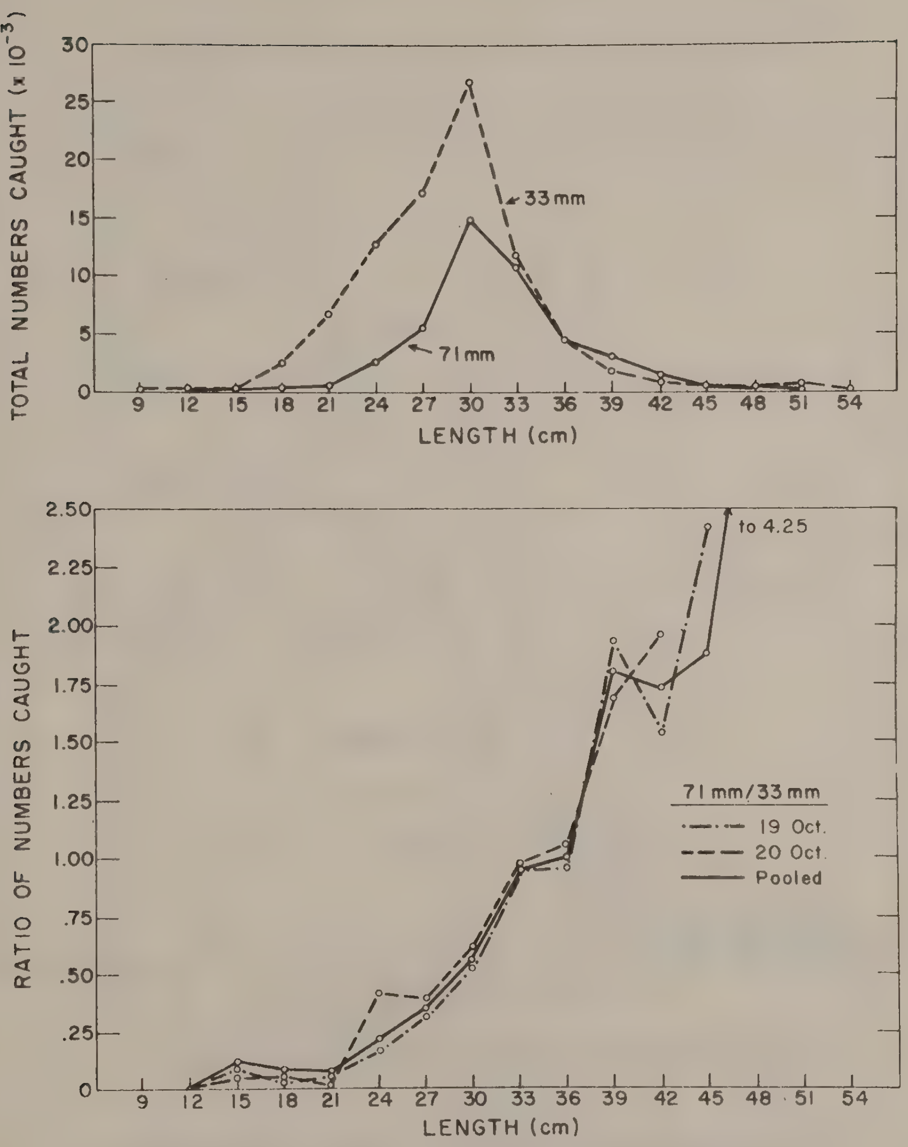

Fig. 3. Retention of silver hake in 33-mm and 71-mm nylon codends, Pt. Judith.

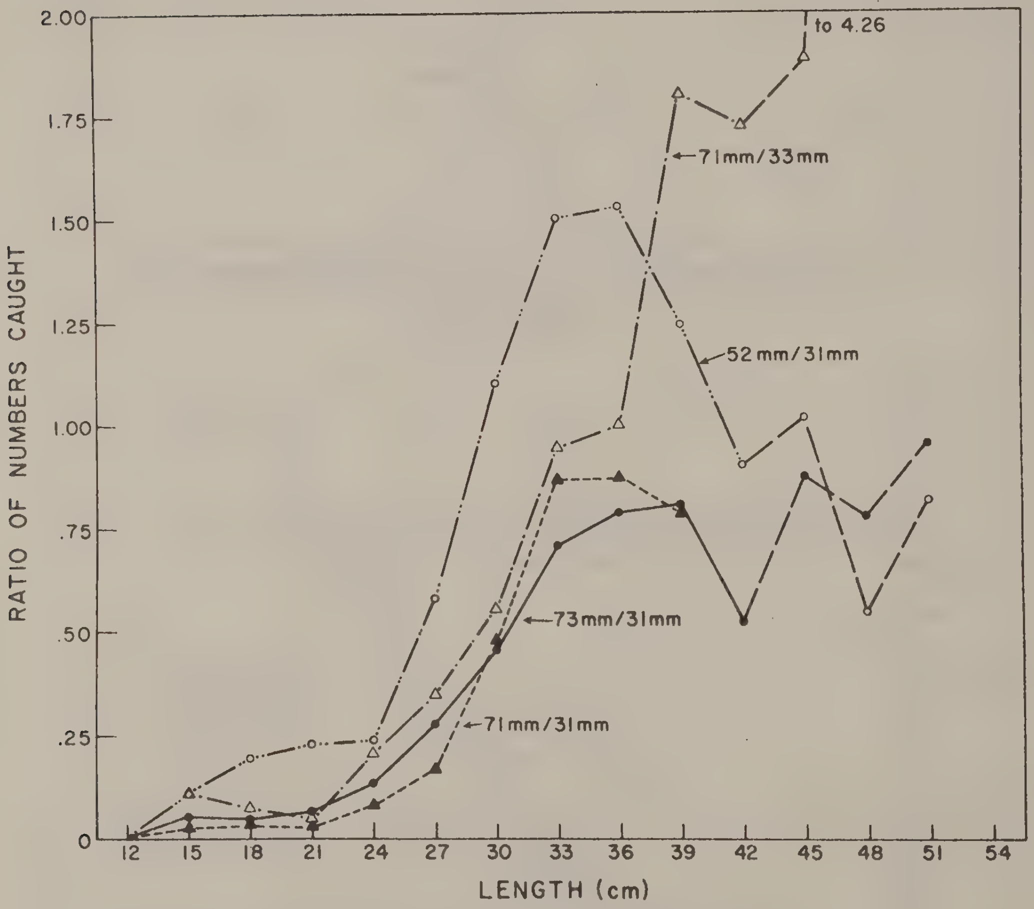

Fig. 4. Estimated retention curves for silver hake in nylon codends.

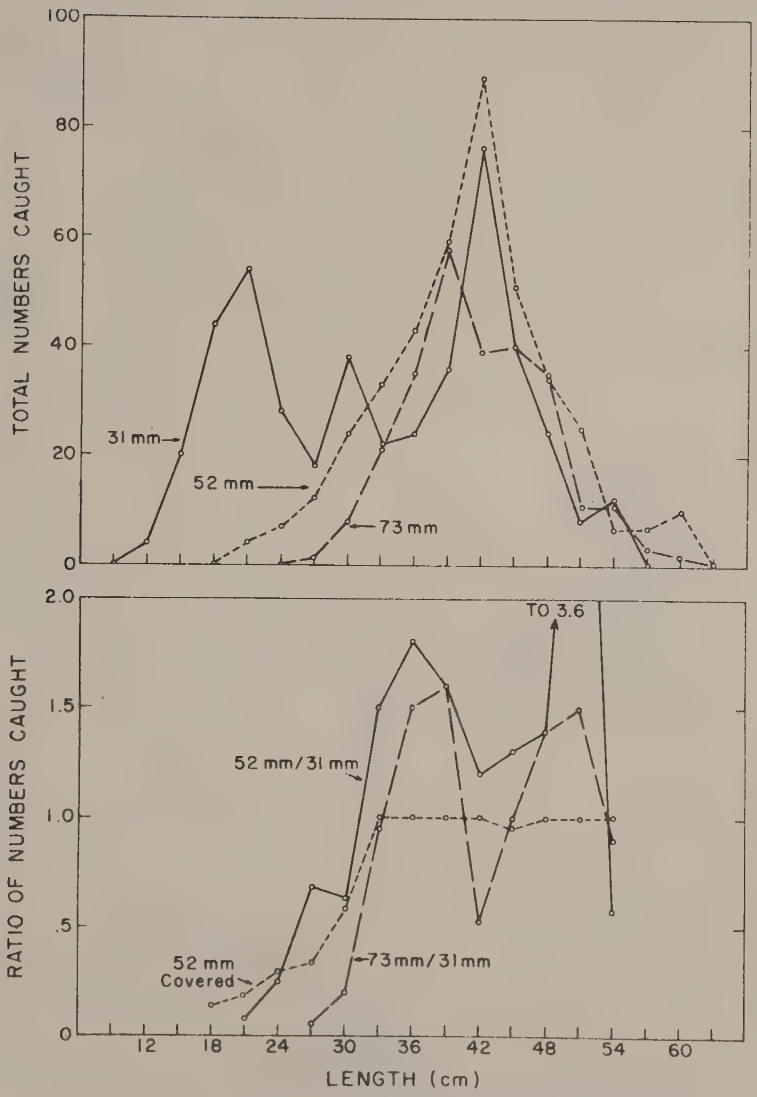

Fig. 5. Retention of red hake in 52-mm and 73-mm nylon codends, *Delaware.*

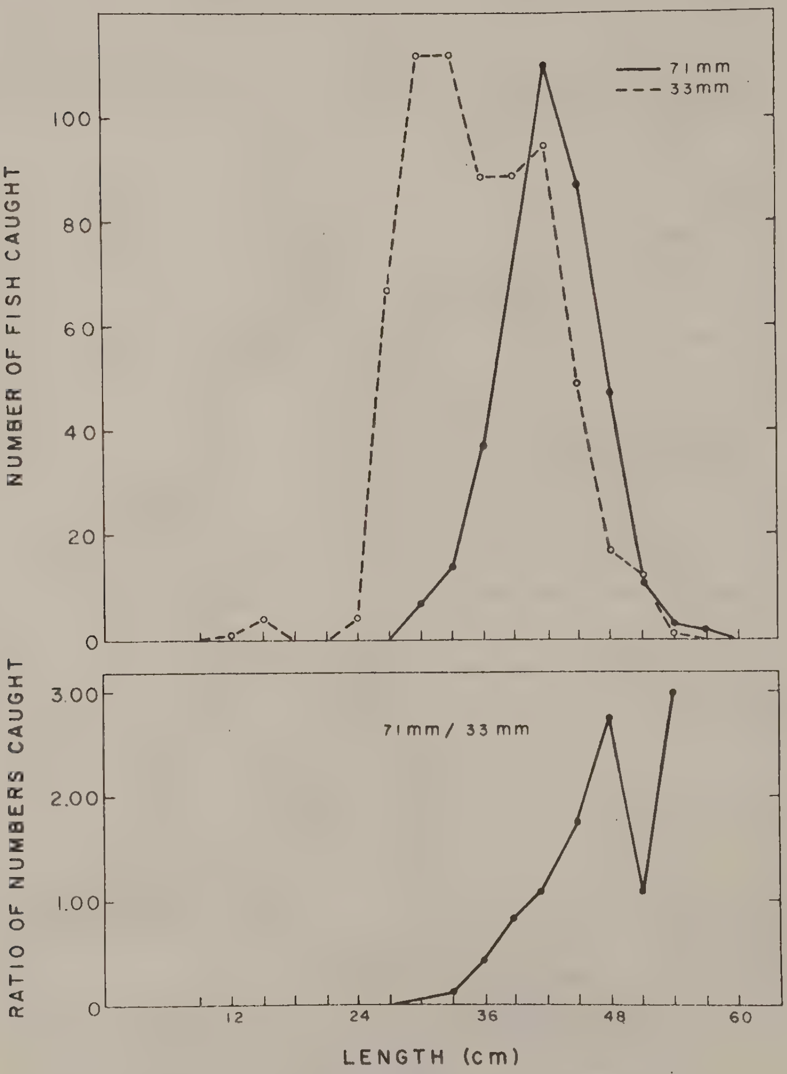

Fig. 6. Retention of red hake in 33-mm and 71-mm nylon codends, Pt. Judith.

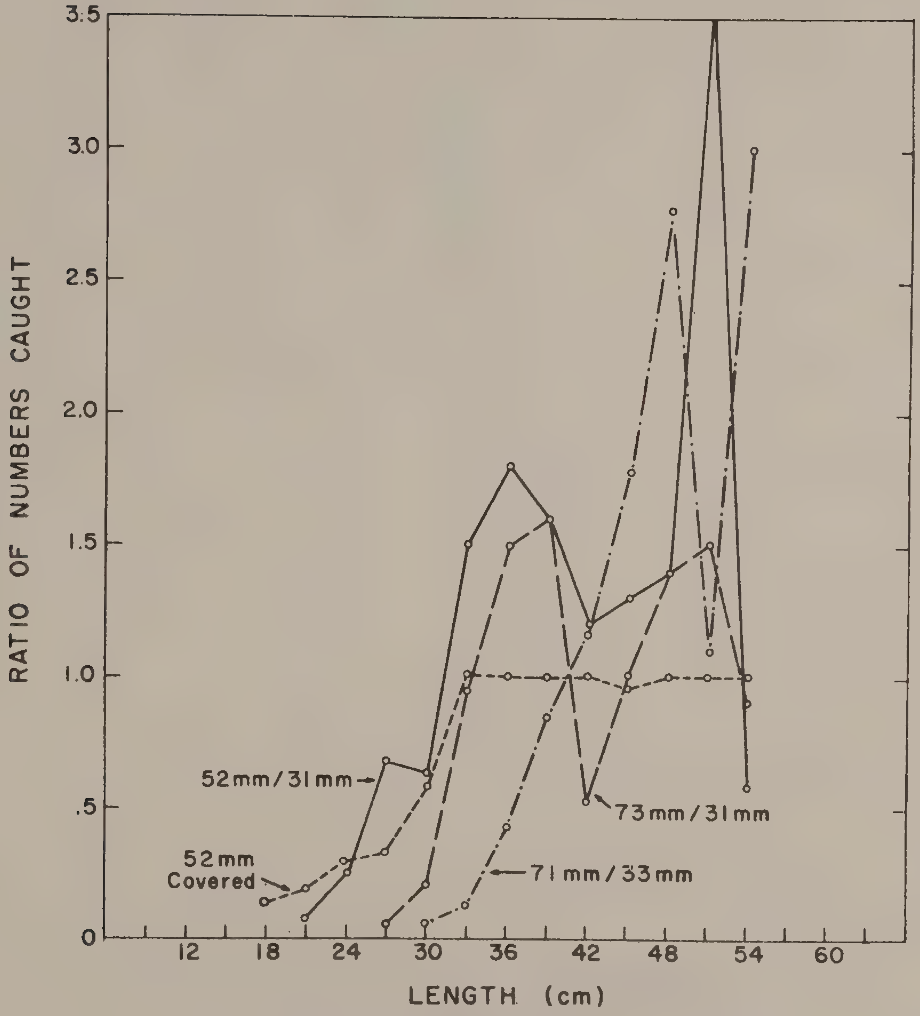

Fig. 7. Estimated retention curves for red hake in nylon codends.

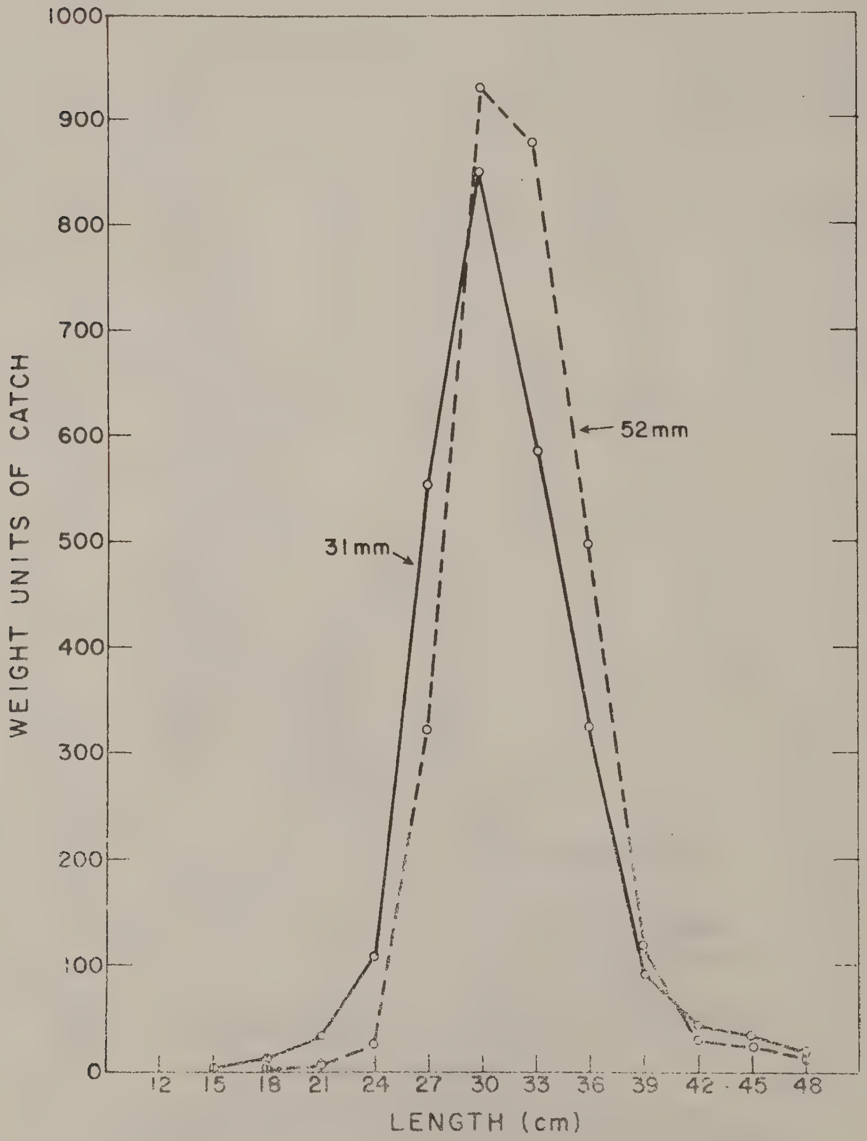

Fig. 8. Estimated weight at length in Pt. Judith catches of silver hake with 31-mm and 52-mm nylon codends.

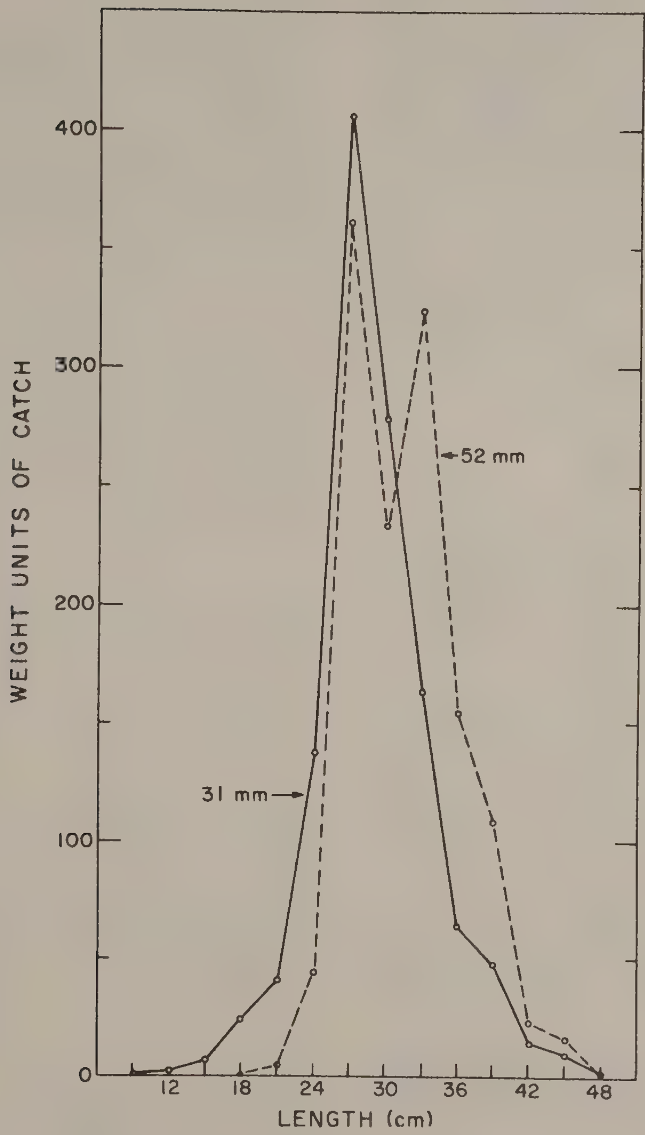

Fig. 9. Estimated weight at length in Pt. Judith catches of red hake with 31-mm and 52-mm nylon codends.

Extensive gilling of fish sometimes is observed in meshes that permit some escapement. In all three experiments, gilling of silver hake in the 71- and 73-mm codends was of the order of 0.1%; certainly not of a magnitude to cause concern. Those that were gilled were 26–41 cm in length, with a modal length of 33 cm, which is somewhat greater than the 50% length. More fish were gilled in the forward parts of the net than in the codend, a fact which does indicate escapement through the forward parts, but is of no practical concern here. These fish were 27–39 cm in length, with a modal length of 33 cm.

Red hake

The catch and selectivity data for each experiment and type of codend are shown in Table 2 and Fig. 5–8. The total number of red hake caught by the *Delaware* and the Pt. Judith vessels (no red hake were caught in the Gloucester experiment) was far less than the number of silver hake caught. The *Delaware* fished known

TABLE 2. Catch and selectivity of red hake, 1964.

	Delaware			Pt. Judith	
Mesh size (mm):	31	52	73	33	71
Length int. mid-point	Numbers caught[a]				
cm					
12	4	—	—	1	—
15	20	—	—	4	—
18	44	—	—	—	—
21	54	4	—	—	—
24	28	7	—	4	—
27	18	12	1	67	—
30	38	24	8	112	7
33	22	33	21	112	14
36	24	43	35	89	37
39	36	59	59	89	73
42	76	89	39	95	110
45	40	51	40	49	87
48	24	34	34	17	47
51	8	25	11	10	11
54	12	7	11	1	3
57	—	7	3	—	2
60	—	10	2	—	—
Total	448	405	264	650	391
Total weight:					
kg	—	—	—	508	189
lb.	—	—	—	1,117	415
No. tows	10	13	18	4	4
Hours towed	6.6	8.8	13.1	4.0	5.6
Weight per hour:					
kg	—	—	—	127	34
lb.	—	—	—	279	74
Ratio of weight per hour[b]	—	—	—	—	0.27
Selectivity:					
50% length (cm)	29.1	25.7	31.0	—	36.5
selection factor	5.6	4.9	4.2	—	5.1

[a] Numbers adjusted to compensate for different fishing time.

[b] Ratio of catch of large mesh to small mesh.

silver hake grounds and red hake were an incidental by-catch. The Pt. Judith vessels fished a ground that usually produces red hake but the fish were scarce the day the experiment took place. Thus, the volume of fish considered in these experiments is less than commercial quantities and less than needed for firm conclusions.

The selection curve of the 52-mm mesh derived from the covered codend tows is not very different from the retention curves of the same size mesh fished without the cover, at least up to the 100% point (Fig. 5). The 50% lengths differ by about 3 cm and the selection factors differ by 0.7. In each case the covered codend values are lower.

Size selection is rather sharp for the 73-mm mesh. The 25–100% retention lengths are within 3 cm, whereas the same span for the 52-mm covered and the 52-mm uncovered codends are 10 cm and 7.5 cm respectively. Also, the retention curve for the 73-mm mesh is displaced to the right of the curve for the 52-mm mesh by only about 4 cm. All of these results are in sharp contrast to those observed for silver hake.

The retention curve for the 71-mm codend used in the Pt. Judith experiments indicates again a rather sharp selection (Fig. 6). We also note a proportionately greater release of smaller fish compared to the 73-mm mesh in the *Delaware* experiments; the 50% points are 37 and 31 cm, respectively (Fig. 7, Table 2).

In all retention curves based on uncovered codends, ratios exceeding unity were observed, and perhaps indicate a higher catching efficiency. However, the ratios from the *Delaware* experiment are quite erratic for lengths greater than about 39 cm, and therefore, do not provide clear-cut results. The data points for the Pt. Judith experiment are somewhat better in this regard, and indicate the same trends as observed for the silver hake.

The total catch per hour for all species in the Pt. Judith experiment was 1,931 kg (4,250 lb.) for the 33-mm mesh codend and 503 kg (1,107 lb.) for the 71-mm mesh codend. This is a rather drastic reduction; however, it is mostly due to the reduction in catch of species other than red hake—silver hake, flounders, butterfish, and skates. The catch of red hake in the 71-mm mesh codend was estimated to be 8% less than the catch in the 33-mm codend. The average length of red hake in the 1964 industrial landings was less than that observed during our experiments; thus, in actual practice the losses would be somewhat greater than 8%.

There was no opportunity to exchange codends between the two Pt. Judith vessels to average out differences in catch rate. Therefore, we must consider the results as provisional.

We have no observations of gilled red hake in the *Delaware* experiment but we made some measurements in the Pt. Judith experiment. The fish gilled only in the 71-mm codend. At the end of a 1.3 hr tow, 62 red hake were gilled in the meshes. The gilled fish ranged from 33 to 46 cm in length with the mode at 42 cm. The codend catch for that tow consisted of 454 kg (1,000 lb.) of silver hake, flounders, miscellaneous fishes, and 113 red hake from 33 to 56 cm long.

Conclusions

Silver hake

Silver hake is the most important single species in the industrial catches off southern New England and is the basis of an important food-fish fishery at Gloucester, Massachusetts (Edwards, 1958; Edwards and Lux, 1958; Edwards and Lawday, 1960; Fritz, 1960).

The results of the experiments make it readily apparent that the 71- and 73-mm meshes release a large proportion of the fish in the 25–35-cm length interval—the size group which forms the bulk of fish available to commercial trawl nets. The larger meshes do not release very many more of the fish less than 25 cm in length than does the 52-mm mesh.

We do not know the magnitude of long-term benefits—the gross gain in weight less natural mortality—which might be obtained by postponing capture with the use of 71- or 73-mm mesh codends. However, judging from preliminary estimates, the growth rate of fish above 25 cm is rather slow and mortality is not low; therefore, it would be rather optimistic to expect the benefits to compensate for the large immediate loss of about 50%.

It is of interest however, to consider the use of 52-mm mesh in place of the 33-mm mesh. The Pt. Judith fishery is particularly concerned, and we have calculated the immediate effects for such a change by applying the retention ratios for the 52-mm mesh estimated from the

Delaware experiments to the average length-frequencies of the Pt. Judith catches in 1964 (Fig. 8). The weight units are in terms of lengths cubed, and do not represent absolute catches, but are assumed to be proportional to them.

A gain of about 8% by weight is estimated for the larger mesh. This is brought about by the apparent increase in catching efficiency, expressed in the retention ratios greater than one which coincide with the peak length frequencies. Almost all fish below 25 cm would be released, but they do not contribute much to the weight of catch.

Red hake

Red hake contribute about 20% of the annual landings from the inshore grounds at Pt. Judith (Edwards, 1958; Edwards and Lawday, 1960). They make up about one-third of the landings in May–July. Therefore, the expected immediate loss with the 71-mm codend would be important to the industrial fishery. Our data for the 71- and 73-mm mesh codends show considerable loss of red hake less than about 30–35 cm, but little loss with the 52-mm codend.

To estimate the effect of a 52-mm mesh on the catch of red hake by the industrial fleet at Pt. Judith, we applied the retention ratios estimated from the 52-mm mesh aboard the *Delaware* to the average length-frequencies of the 1964 Pt. Judith red hake landings. The weight units are in terms of lengths cubed and are assumed to be proportional to the absolute catches (Fig. 9).

The immediate effect of the larger mesh is a loss estimated to be about 8%. A large proportion of the fish below 24 cm would be released and enough of the sizes smaller than 33 cm to offset the gain in catch of fish between 33 cm and 42 cm.

Acknowledgements

The authors wish to acknowledge the fine cooperation of William E. Ragusa, Captain of the *Frances R.*, John Dykstra, Captain of the *Nyanza,* Robert D. Smith, Captain of the *David D.*, and their crews, who enabled these experiments to be conducted effectively.

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Reprinted from
Proceedings of the
GULF AND CARIBBEAN FISHERIES INSTITUTE
Nineteenth Annual Session, November, 1966
100-107

Tropical Atlantic Tuna Investigations, 1966[1]

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Abstract

The Atlantic Tuna Convention, approved by representatives of 17 nations at a meeting in Rio de Janeiro in May 1966, establishes a framework for the investigation and possible management of the Atlantic tuna fisheries. The harvest from these fisheries has increased rapidly in the last decade and recent developments suggest that this growth will continue. To date, tuna research has been carried out at a number of national laboratories, but knowledge of the biology of most species is rudimentary. Information of the most elementary nature required for scientific management of the fisheries is generally incomplete or unavailable. Research programs in stock composition and environmental studies at the Tropical Atlantic Biological Laboratory are described. Cooperative programs with West African laboratories and with the Caribbean Fisheries Development Project of the United Nations Special Fund are discussed.

THE OBJECTIVES OF THIS REVIEW ARE:

1. To outline the present development of the Atlantic tuna fisheries
2. To discuss the function of the Atlantic Tuna Convention in the conservation of tuna stocks
3. To list certain scientific knowledge needed to regulate these stocks for maximum sustained yield.

Tuna catches from the Atlantic Ocean have nearly doubled in the last decade. Landings of tunas and bonitos, recorded as 180,000 metric tons in 1954, were 330,000 metric tons in 1964 (FAO, 1966). A large part of this catch was taken from the tropical and subtropical Atlantic Ocean. Several nations recently have added new vessels to their Atlantic tuna fleets. Probably fishing pressure on Atlantic tuna stocks will continue to increase, with a possible resultant rise in catch.

ATLANTIC TUNA FISHERIES

Presently the Atlantic tuna fisheries are carried out by large modern vessels of several nations and by small vessels of numerous indigenous fishing fleets. The rapid increase in catches in the last decade has resulted from the development of new fisheries and, to a lesser extent, from growth of older, established fisheries.

Of the five principal large-scale tuna fisheries in the Atlantic Ocean, two have been categorized by the species selected and three by the fishing gear used (Shomura, 1966). These fisheries are: the northeast Atlantic bluefin tuna, the Bay of Biscay albacore, the western Atlantic purse-seine, the Cuban live-bait, and the Japanese long-line.

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[1] Contribution No. 48, Tropical Atlantic Biological Laboratory, Bureau of Commercial Fisheries, Miami, Florida.

The northeast Atlantic bluefin tuna fishery extends from the coast of Norway and the North Sea to Spain, Portugal, and Morocco (Tiews, 1963). The fishery is seasonal, from about May to October, and lasts only 2 to 3 months in any one area. The fish are taken by traps along the coasts of Spain, Portugal, and Morocco; by hooks and lines off Portugal and France and in the North Sea; and by purse seines off Norway. Landings have declined in the last decade. Catches by representative countries totaled 38,300 metric tons in 1955 but dropped to 15,600 metric tons in 1964 (Table 1). In recent years the bulk of the catch was taken by Spain and Morocco; catches were few in the northern areas of the fishery.

The Bay of Biscay albacore fishery, the largest of the older tuna fisheries, was the largest tuna fishery in the Atlantic until the Japanese long-line fishery gained first place in the late 1950's. The fishery is seasonal. Albacore appear in the southern Bay of Biscay in June and remain until November (Postel, 1963). Before 1946, albacore were caught principally by trolling but pole and line fishing (introduced by the French in 1947) is now the principal method. Albacore catches by Spain and France increased from 39,000 metric tons in 1956 to 45,700 metric tons in 1963.

TABLE 1

CATCHES OF SELECTED ATLANTIC OCEAN TUNA FISHERIES AND TOTAL ATLANTIC CATCHES OF TUNAS, 1955-1964

Year	Fishery					
	NE Atlantic bluefin[1]	Bay of Biscay albacore[2] (10^3 metric tons)	Cuban tuna[3]	NW Atlantic tuna[4]	Japanese Atlantic long-line[5] (10^3 fish)	Atlantic tuna, bonito, and skipjack[6] (10^3 metric tons)
1955	38.3	30.5	1.4	0.4	—	180.0
1956	24.5	39.0	1.5	0.2	13	180.0
1957	34.6	37.2	1.9	0.5	299	200.0
1958	30.6	49.8	0.9	1.1	859	230.0
1959	21.9	46.9	1.7	1.3	1495	230.0
1960	21.2	46.5	3.2	0.6	1702	280.0
1961	19.7	38.1	3.0	1.0	1653	290.0
1962	24.5	44.0	1.2	3.2	2488	270.0
1963	11.1	45.7	2.4	7.4	2373	310.0
1964	15.6	37.4	1.6	9.2	—	330.0

[1] FAO, 1966. Totals include catches reported by Morocco, Denmark, France, Germany, Norway, Spain, Sweden, Netherlands, and Belgium.

[2] FAO, 1966. Totals include catches reported by France and Spain.

[3] Suarez and Duarte, 1961 (years 1955-59); FAO, 1966 (years 1960-64).

[4] Wilson, 1965 and Wilson, personal communication. Totals are U.S. catches of bluefin tuna and skipjack tuna from the Atlantic including catches by traps and other gear (Fishery Statistics of the U.S., 1955-64).

[5] Wise, in press.

[6] FAO, 1966.

The African surface fishery for yellowfin tuna and skipjack tuna began off Senegal in late 1955. By 1963, the fishing area extended south to Angola and the fleet consisted of 90 French, 50 Spanish, 7 Japanese, and a few Portuguese live-bait boats (Shomura, 1966). Recently, Yugoslavian and Japanese purse seiners entered the fishery. In addition to yellowfin tuna and skipjack tuna, small quantities of bigeye tuna also were taken.

African surface-fishery statistics are not sufficiently accurate to report year-by-year growth. In 1963, total landings were 25,300 metric tons (Shomura, 1966).

In the western Atlantic Ocean, bluefin tuna for many years formed the basis of a small fishery off the New England coast. A purse-seine fishery was established in the late 1950's and the fishery was extended to offshore waters (Wilson, 1965). Skipjack tuna were discovered in commercial quantities and by 1964 made up 55% of the total landings (Shomura, 1966). The U.S. Atlantic purse-seine landings increased from 200 metric tons in 1958 to 10,000 metric tons in 1964, but catches were considerably less in 1965 and 1966.

A small pole-and-line fishery for skipjack tuna, blackfin tuna, and little tuna developed in Cuba in 1940 (Suarez and Duarte, 1961). Current annual landings from the Cuban live-bait fishery, supplemented by a small long-line fishery, are reported between 1,000 and 3,000 metric tons. Expansion of the Cuban fishing fleet in recent years may cause landings to increase.

The Japanese long-line tuna fishery extends across the entire tropical and subtropical Atlantic Ocean (Shiohama et al., 1965). The fishery started with an exploratory cruise by a Japanese research vessel in 1955; the commercial fleet began fishing in the tropical Atlantic in 1957. Over 90% of the catch in numbers of fish consisted of yellowfin tuna, albacore, and bigeye tuna. Marlins made up less than 5% of the catch through 1959 but increased to about 10% in 1962 and 1963. Landings of the long-line fishery totaled 118,300 metric tons in 1964 (FAO, 1966).

ATLANTIC TUNA CONVENTION

Because the Atlantic tuna fisheries are oceanwide and involve a number of nations, conservation measures must be undertaken at the international level. In 1960 an international convention for the conservation of tunas was proposed by the Commission for Technical Cooperation in Africa/Scientific Council for Africa (CCTA/CSA). In May 1966, delegates from 17 nations drafted an Atlantic Tuna Convention. This convention is unique in several ways:

1. It includes all waters of the Atlantic Ocean and adjacent seas. This area is larger than that covered by any other international fishery convention.

2. It includes many species of Atlantic tunas and tuna-like fishes (at least 20 species), and also bait fishes used in tuna fishing. Exceptions are the mackerels (genus *Scomber*) and the families Trichiuridae and Gempylidae.

3. Membership may be greater than that of any existing international fishery body. All members of the United Nations are eligible.

Almost all nations whose fishermen harvest Atlantic tunas and whose industries process tunas from this area, and those with sea coasts contiguous to areas where fish are taken, are expected to become parties.

Once approved, the Convention will remain in force for at least 10 years; thereafter it may be terminated by a majority decision. Panels to study individual species can be established and a commission can recommend regulations designed to maintain stocks at levels which will permit the maximum sustainable catch.

RESEARCH REQUIREMENTS

Several critical needs will face the Atlantic Tuna Commission as it prepares for management of the Atlantic tuna resources. First is the need for adequate catch statistics, which are basic to the management of any fishery. Because Atlantic tuna fishing is practiced by vessels from several nations, no single organization has the responsibility—and necessary authority—to collect and maintain records. Often national records are inadequate (Chapman, 1963). The Atlantic Tuna Commission specifically will be charged with the collection and analysis of statistics relating to conditions and trends of tuna resources in the area covered by the Convention.

Second is the need for knowledge of stock composition. Distinct population subdivisions (unit stocks) fall into two main categories: geographically isolated groups separated from each other by migration barriers, and reproductively isolated groups which inhabit the same general locality, but possess different vital statistics (Parrish, 1964). Methods for defining these population units can be direct (tagging, exploratory fishing, egg and larval surveys) and indirect (serological biochemical, morphometric.) Results of such studies have important implications for fishery management.

Almost nothing is known about the existence of separate stocks of Atlantic tunas, nor is it known whether a single stock is available to more than one fishery. Possibly albacore in the north and south Atlantic Ocean or yellowfin tuna in the eastern and western tropical Atlantic Ocean represent discrete populations. Several species caught by the subsurface long-line fishery are also taken in various surface fisheries.

Third is the need for knowledge of the relation between environmental fluctuations in time and space and the distributions and abundance of tunas. An understanding of this relation represents a potentially great contribution to the fishing industry from biology and oceanography. Scientific research will become meaningful to fisheries when it can predict the quantities of fish and the locations and periods of greatest availability. At present, our knowledge of the ocean environment is inadequate — information about the climate of the oceans and how it is controlled is limited, and we need to learn much more about the fish in the oceans and their response to environmental stress and variation.

At present, research on tuna in these critical areas of catch statistics, stock composition, and environmental effects is being carried out at laboratories in many countries on both sides of the Atlantic Ocean (Table 2).

TABLE 2

PRINCIPAL LABORATORIES AND AGENCIES CONCERNED WITH RESEARCH ON ATLANTIC TUNAS (FAO, 1965; AND OTHER SOURCES).

Country	Station	Location
Angola	Centro de Biologia Piscatoria. Instituto das Industrias de Pesca de Angola	Baia Farta (Benguela) Luanda
Congo-Brazzaville	Centre ORSTOM* de Pointe-Noire	Pointe Noire
Ghana	Fisheries Division, Ministry of Agriculture	Tema
Republic of Ivory Coast	Centre de Recherches Oceanographiques (ORSTOM staff)	Abidjan
	Service des Peches Maritimes	Abidjan
Senegal	Center d'Oceanographie de Dakar (ORSTOM)	Thiaroye (Dakar)
Sierra Leone	Fisheries Division	Freetown
South Africa	Division of Sea Fisheries	Capetown
	South African Museum	Capetown
Argentina	United Nations Development Programme in Argentina	Buenos Aires
Brazil	SUDENE	Recife
	Marine Biology Station, University of Ceara	Fortaleza
	Univ. of Sao Paulo	Santos
	Divisao de Caca e Pesca	Santos
Venezuela	Fisheries Agency	Caracas
Barbados	United Nations Caribbean Fishery Development Project	Bridgetown
United States of America	Tropical Atlantic Biological Laboratory	Miami
	Institute of Marine Sciences	Miami
	Exploratory Fishing and Gear Research Base BCF	Pascagoula
	Woods Hole Oceanographic Institution	Woods Hole

	Exploratory Fishing and Gear Research Base BCF	Gloucester
	BCF Ichthyological Laboratory	Washington, D. C.
Denmark	Fishery Research Institute	Charlottenlund-Slot
France	Museum National d'Histoire Naturelle	Paris
	ORSTOM*	Paris
	Institut des Peches de Sete	Sete, Herault
	Office Scientifique et Technique des Peches Maritimes	La Rochelle (Charente Maritime)
Norway	Institute of Fisheries Research	Bergen
Portugal	Centro de Biologia Piscatoria	Lisbon
	Instituto de Biologia Maritima	Lisbon
Spain	Laboratorio del Instituto de Investigaciones Pesqueras de Cadiz	Cadiz
Canada	St. Andrews Biological Laboratory	St. Andrews, N. B.
Japan	Nankai Regional Fisheries Laboratory	Kochi
U.S.S.R.	VNIRO	Moscow
	Atlant NIRO	Kaliningrad
Cuba	University of Villanueva	Havana
	Instituto Cubano de Investigaciones Tecnologicas	Havana
	Fisheries Research Center	Havana
Germany	Institut fur Kusten und Binnenfischerei der Bundesforschungsanstalt fur Fischerei	Hamburg-Altona

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*Office de la Recherche Scientifique et Technique Outre-Mer

The U. S. Bureau of Commercial Fisheries Laboratory in Miami (Florida) conducts a variety of studies on the biology and ecology of tropical Atlantic tunas. Some of them are:

1. Cooperative biological sampling programs with laboratories in Republic of Ivory Coast, Congo-Brazzaville, Senegal, Ghana, Angola, and Sierra Leone which provide information on the landings and samples from the catch.

2. Studies to determine the feasibility of using enzymes as genetic markers characterizing subpopulations of tropical Atlantic tunas. The object of this study (under a contract with the University of Miami) is to determine whether certain enzymes occur in genetically controlled patterns and whether these patterns differ in frequency among geographically isolated stocks of fish. Tunas from three general areas are being studied: the eastern Atlantic, the western Atlantic (including the Caribbean), and the Pacific. The enzymes to be assayed are lactic acid dehydrogenase (LDH), malic acid dehydrogenase (MDH), hexose-6-phosphate dehydrogenases, xanthine dehydrogenase, and the non-specific esterases.

3. Studies in biological and physical oceanography designed to understand better and thus eventually predict the distribution, abundance, and availability of tunas. Field work in 1963 to 1965 was done in the eastern tropical Atlantic. The Bureau of Commercial Fisheries vessel GERONIMO made four cruises to the Gulf of Guinea and off the northwest coast of Africa. The first and second cruises were part of the EQUALANT surveys of the International Cooperative Investigations of the Tropical Atlantic (ICITA). Vernon Brock and Thomas S. Austin, successive directors of the laboratory, served as international coordinators of the ICITA study, and scientists at the laboratory processed data and samples. Studies of the distribution and ecology of tuna larvae and of primary and secondary organic production were included.

Field work in 1965 and 1966 was also performed in the western tropical Atlantic. Procedures were similar to those followed in the eastern Atlantic — combined fishery and oceanography surveys were made to achieve a better understanding of the observed distribution and concentrations of tunas.

On a fishery-oceanography survey in the spring of 1966, the research vessel UNDAUNTED discovered a concentration of skipjack tuna near St. Vincent and Grenada Islands in the southern Lesser Antilles. The distribution of the tuna schools appeared to be related to the presence of turbulence and biological enrichment west of the islands. Repeated surveys, in cooperation with the Caribbean Fisheries Development Project of the United Nations Special Fund, are planned to determine the distribution of fish seasonally in this particular area and how this distribution relates to environmental conditions.

The research programs of national laboratories like the Tropical Atlantic Biological Laboratory and the establishment of the Atlantic Tuna Commission represent an attempt to combine scientific knowledge and international cooperation to manage a biologically complex fishery resource. The success of this attempt will no doubt be judged at future meetings of the Gulf and Caribbean Fisheries Institute.

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Reprinted from Crustaceana, vol. 12, part 3, 1967

A NEW SPECIES OF *CALANOPIA* (COPEPODA, CALANOIDA) FROM NERITIC WATERS OF FRENCH OCEANIA, CENTRAL PACIFIC

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During the examination of plankton samples collected by the Bureau of Commercial Fisheries in the area of the Marquesas Islands, an apparently undescribed species of *Calanopia* was found. It was abundant in samples from the bays of the Marquesas but also occurred at stations as far as 80 to 100 miles from the nearest island (Jones, 1962 and unpublished). It has also been found (personal observation) in the neritic waters of the Society and Tuamotu Islands.

When Bowman (1957) described *C. biloba,* he brought to nine the known species of *Calanopia.* He concluded that only *C. americana* Dahl and *C. biloba* were to be found in the Atlantic. *C. biloba* was described by him from "Carnegie" station 32 in the Caribbean after Wilson (1942) had, in error, identified the material as *C. elliptica* (Dana). Wilson stated that he also found *C. elliptica* near the Samoan Islands in the Pacific. However, a plankton sample collected by the Bureau of Commercial Fisheries in the harbor at Pago Pago, American Samoa ("Charles H. Gilbert" cruise 55, station 105, March 15, 1962), contained no *C. elliptica* but did contain about 40 or 50 specimens of *C. biloba.* Dr. Bowman has kindly confirmed this identification and stated that it is possible that his specimens of *C. biloba* did not come from the Caribbean at all. He has never found it in other plankton samples from that sea (personal communication). In view of this new Pacific record the type locality of *C. biloba* appears to need confirmation.

The new species from the Marquesas Islands is named in honor of the late Mr. R. B. Seymour Sewell of Cambridge, England.

Calanopia sewelli n. sp.

Synonymy. — *Calanopia* sp., Jones, 1962: 224.

Locality and materials. — Lat. 8° to 11° S long., 138° to 141° W, in the vicinity of the Marquesas Islands; in the bays and neritic waters of those islands. Abundant in many samples from the following cruises: "Charles H. Gilbert" cruise 30, August to September 1956; cruise 35, October to December 1957; cruise 38, February to April 1958; "Hugh M. Smith" cruise 43, January to February 1958; cruise 45, March to May 1958. At offshore stations it was apparently limited to the upper 100 m.

Types. — Type material has been deposited in the United States National Museum as follows: female holotype (USNM 112649) "Charles H. Gilbert" cruise 38, station 23 in Hakaea Bay, Nuku Hiva, February 26, 1958. Male allotype (USNM 112650) same station. Four female paratypes (USNM 112651) same station. Two female paratypes (USNM 112652) "Charles H. Gilbert" cruise 30, station 36-2, 10° 00′ S 139° 41′ W September 3, 1956. One male paratype (USNM 112652) same station. Two male paratypes (USNM 112651) cruise 38, station 23 as above. Numerous unsorted paratype material (USNM 112653) "Hugh M. Smith" cruise 43, station 20, Hiva Oa, January 21, 1958.

Measurements. — Measurements of total length were made from the frontal margin of the head to the end of the caudal furca. The telescoped portions of the abdominal segments were not included in the total length or the cephalothorax-abdomen ratio, but were included in the ratios of the lengths of the abdominal segments. Pertinent measurements of the female holotype, six female paratypes, the male allotype, and three male paratypes are presented in table I.

TABLE I

Total length, cephalothorax-abdomen ratios, and abdominal segment ratios of *Calanopia sewelli* n. sp.

	Total length mm	Cephalothorax-abdomen ratio	Abdominal segment ratios 1	2	3	4	5	Furca
Females								
Holotype	2.33	2.28 : 1	38.1	38.1	—	—	—	23.8 = 100
Paratype	2.50	2.30 : 1	37.2	37.2	—	—	—	25.6 = 100
Paratype	2.34	2.38 : 1						
Paratype	2.26	2.51 : 1						
Paratype	2.21	2.43 : 1						
Paratype	2.12	2.49 : 1						
Paratype	2.04	2.44 : 1						
Males								
Allotype	2.17	2.14 : 1	17.6	20.3	18.9	16.2	8.1	18.9 = 100
Paratype	2.11	2.20 : 1						
Paratype	2.14	2.25 : 1						
Paratype	2.37	2.13 : 1						

DESCRIPTION

Female. — The head (fig. 1) is separated from the first thoracic segment; segments four and five of the thorax are fused, but a line visible in dorsal view marks the zone of fusion. Two small eye spots (figs. 1, 2) are visible near the anterior lateral margins of the head and retrorse cephalic hooks are present on the lateral margins just anterior to the eye spots. The divergent filaments of the rostrum are visible in dorsal view and prominent in lateral view (figs. 1, 3, 4). The posterior lateral processes of the fifth thoracic segment (fig. 2) are produced into symmetrical points which reach to a line including 38 percent of the length of the genital segment. As in other members of the genus, the second abdominal segment appears never to telescope into the genital segment. The genital segment is symmetrical in dorsal view, and the ventral surface is without processes (fig. 5). The rami of the caudal furca (fig. 2) are slightly asymmetrical, the right one having a more concave inner margin. In some specimens the right ramus is slightly longer than the left. Each ramus bears five major setae and a minute inner one, all without distinction (figs. 1, 2).

The first antenna (fig. 6), when pressed against the body, reaches almost to the posterior margin of the genital segment. The distal margin of fused segments 9-11 is angularly sigmoid, as in *C. biloba* (cf. Bowman, 1957).

The second antenna (fig. 7) differs from that of other species which have been described in having an extensive patch of hair on the inner margin of the distal end of the proximal exopodal segment, and in having one seta on the proximal and two setae on the second endopodal segments.

The mandibular blade (fig. 8) bears two large sharp spines, three blunt processes with bifid tips, and two pairs of slender spines.

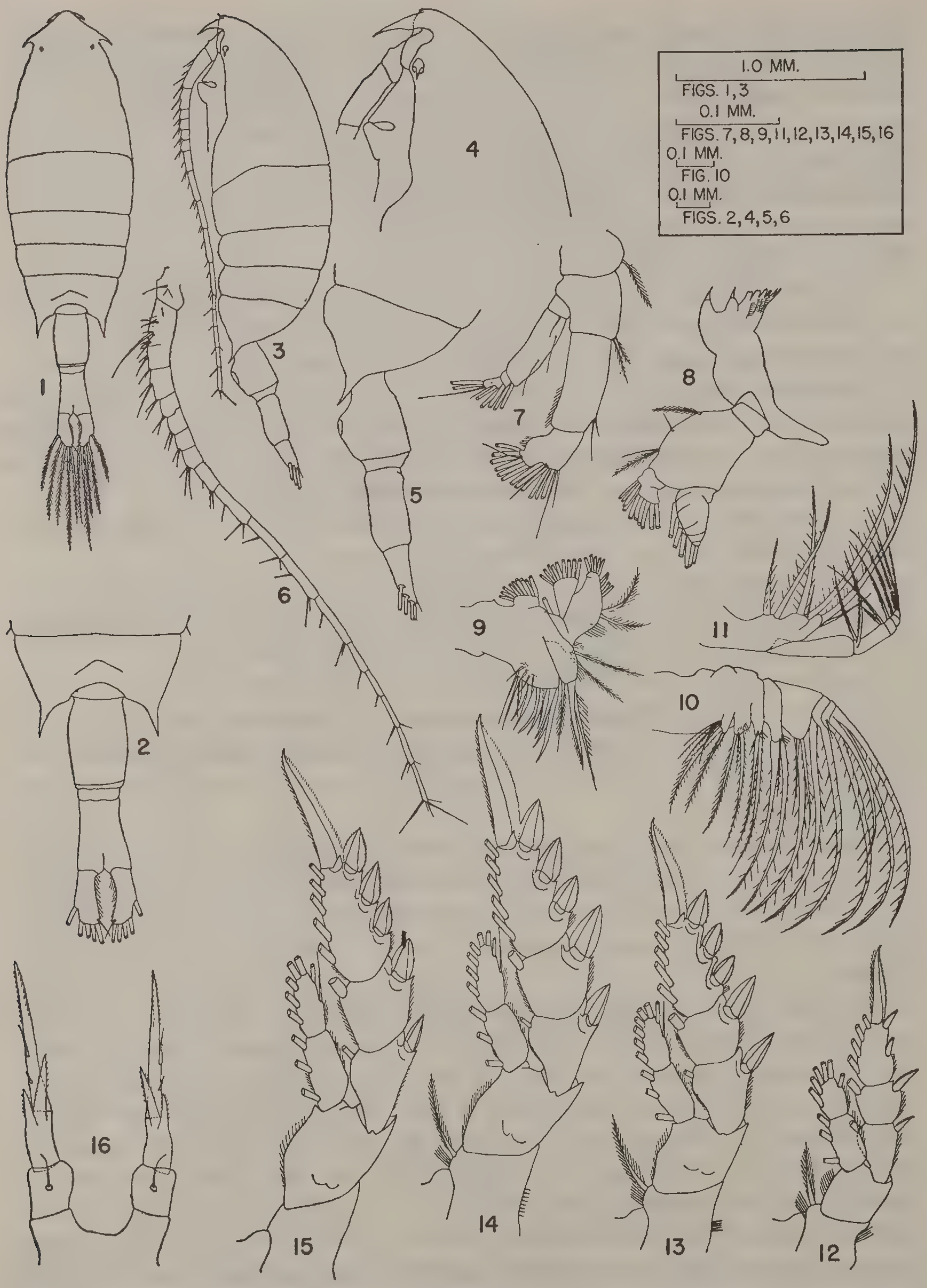
The first and second maxillae (figs. 9, 10) are as in *C. biloba* Bowman (1957). The maxilliped (fig. 11) appears to differ from that of *C. biloba* in having a third small seta on the middle lobe of the first basipodal segment.

The first four swimming feet (figs. 12-15) have three exopodal and three endopodal segments. The four external spines of the exopod of the first foot (fig. 12) are without lateral blades but are denticulate on the distal margins. The five external spines of the other exopods have flat, lateral blades, serrate on both margins.

The external margin of the proximal basipodal segment of the first foot (fig. 12) has a group of four or five hairs near the disto-lateral corner. The same margin of the second foot (fig. 13) bears five small spines; that of the third foot (fig. 14) eight small spines. The same margin of the fourth foot (fig. 15) is without spines or hairs.

The female fifth feet (fig. 16) are three-segmented. The short proximal segment bears a single seta on the posterior surface. The second segment bears two large spinous processes arising from the posterior surface; the inner one points slightly mediad; the outer, smaller one points slightly laterad. Each bears two rows of denticles near the margins in posterior view. The distal segment is long and pointed and bears two spines arising at points one-fifth and two-fifths of the segment length from the proximal end.

Male. — The cephalothorax of the male (fig. 17) is like that of the female in most respects. The rostral filaments are not visible in dorsal view (fig. 17), and the lateral cephalic hooks, in side view (fig. 18), point more ventrad than in the female. The abdomen is symmetrical in all respects and without processes (figs. 17, 19). The caudal rami (fig. 20) are symmetrical and have straight, hairy inner margins. The caudal setae are as in the female.


1.0 MM.
FIGS. 1,3
0.1 MM.
FIGS. 7, 8, 9, 11, 12, 13, 14, 15, 16
0.1 MM.
FIG. 10
0.1 MM.
FIGS. 2, 4, 5, 6
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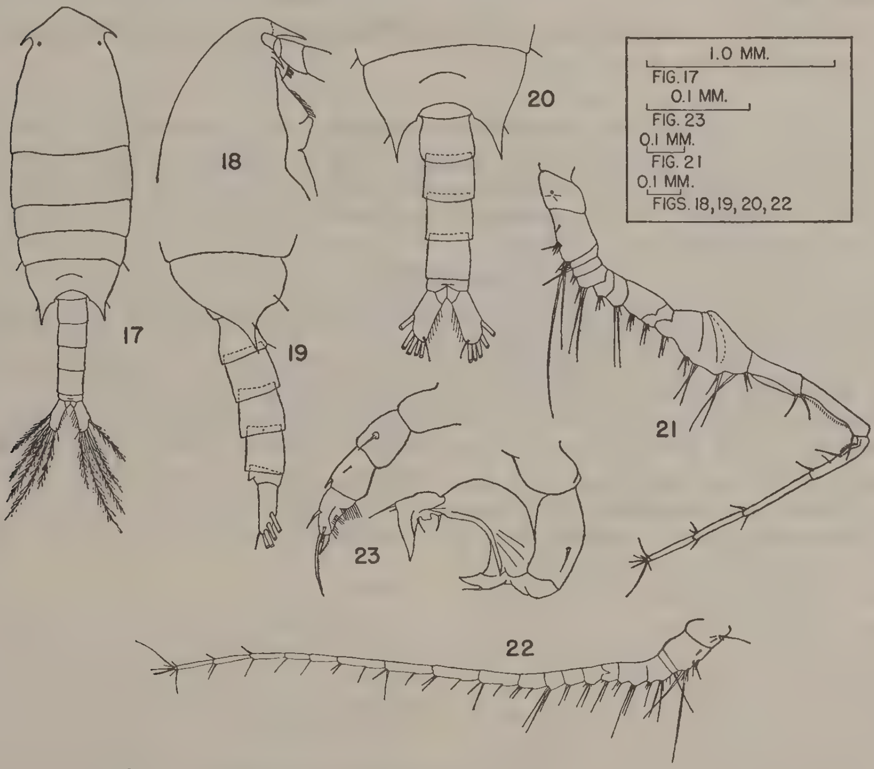
Figs. 1-16. *Calanopia sewelli* sp. nov., adult female. 1, dorsal view; 2, fourth and fifth thoracic segments and abdomen, dorsal view; 3, lateral view; 4, cephalic region, lateral view; 5, fourth and fifth thoracic segments and abdomen, lateral view; 6, first antenna; 7, second antenna; 8, mandible; 9, first maxilla; 10, second maxilla; 11, maxilliped; 12, first foot; 13, second foot; 14, third foot; 15, fourth foot; 16, fifth foot. Figures 1 and 2 are from the holotype. All others are from a 2.50 mm paratype.

The right first antenna of the male (fig. 21) is geniculate with segments 13 to 16 partially fused and swollen; segment 18 is pectinate; segments 19 to 21 are fused and 19 is pectinate. On the left antenna (fig. 22), the distal margin of fused segments 9-11 is strongly indented.

The chelate, right fifth foot (fig. 23) is three-segmented. The proximal segment bears a single seta on the posterior surface; the second segment forms the thumb and palm of the chela. The thumb is sharp with a small seta on the lateral margin. The concave margin of the palm is smooth and without knobs or processes. The distal segment opposes the second segment with a triangular finger. The inner (with respect to the chela) margin bears a small square process with a single seta distal and another proximal to it. The outer (with respect to the chela) margin of the distal segment forms a 90° angle, with two unequal setae at the apex.



Figs. 17-23. *Calanopia sewelli* sp. nov., adult male. 17, dorsal view; 18, cephalic region, lateral view; 19, fourth and fifth thoracic segments and abdomen, lateral view; 20, fourth and fifth thoracic segments and abdomen, dorsal view; 21, right first antenna; 22, left first antenna; 23, fifth feet. All figures are from the allotype.

The left fifth foot is three-segmented. The proximal segment bears a single seta on the posterior surface; the second segment bears a small seta on the posterior surface and a short spine near the disto-lateral margin. The distal segment has a patch of hair on the inner margin; a short, inner, serrate, apical spine; a long, outer, apical spine with serrate inner margin; a short, smooth spine arising on the posterior surface, and a longer, smooth spine on the outer margin.

Remarks. — The female of *Calanopia sewelli* resembles *Calanopia thompsoni* A. Scott in having lateral cephalic hooks but can be distinguished from that species by the absence of a ventral process on the genital segment, by the greater relative length of the distal segments of the fifth feet, and by the asymmetry of the caudal rami.

The male of *C. sewelli* also resembles *C. thompsoni* but can be distinguished from it by the form of the fifth feet.

ZUSAMMENFASSUNG

Calanopia sewelli n. sp. wird aus dem Seichtwasser um die Gesellschafts-, Marquesas- und Tuamotu-Inseln beschrieben. *C. sewelli* hat Seitenhaken wie *C. thompsoni* A. Scott. Das Genitalsegment des Weibchens besitzt keinen Ventralfortsatz, die Furka ist asymmetrisch.

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Received for publication 29 June 1965.

Reprinted from ENVIRONMENTAL Science & Technology

Vol. 1, May 1967, Pages 417–424

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Preconcentration for Trace Analysis of Sea Waters

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■ The chemical characterization of seawaters by trace-element content usually requires selective preconcentration to produce samples suitable for analysis. Phase-distribution methods which have been used for this purpose are briefly reviewed. Evaporation of the water produces a solid sufficiently concentrated for highly sensitive neutron activation techniques. Liquid-solid and liquid-liquid phase distribution provide greater concentration factors and selectivity and are used in conjunction with less sensitive methods of analysis. A simple procedure involving coprecipitation with alkaline earth salts followed by solvent extraction of transition-metal dithiocarbamates is proposed for use aboard ships at sea. With this procedure, recoveries of manganese, iron, nickel, cobalt, copper, zinc, and lead were shown to be in excess of 90%. Selective concentration of cesium and rubidium by adsorption on ammonium molybdophosphate crystals is suggested as preparation for flame emission or atomic absorption analysis.

Interest in the chemical characterization of seawaters is growing as increased attention is directed toward marine resources. As a chemical solution, sea water contains approximately 3 to 3.5% dissolved solids, primarily halides, sulfates, and carbonates of sodium, magnesium, calcium, potassium, and strontium. The concentrations of these substances vary so little that they have been classed as conservative properties of sea water. In addition to these constituents, traces of at least 50 other elements have been detected.

An analyst, faced with the determination of heterogeneities in the composition of sea waters, has two ways to approach his problem: (1) measurement of small differences at the relatively high concentrations of the major constituents, or (2) measurement of relatively large differences in the concentrations of the trace constituents. In the first case, the principal difficulty is to achieve precision sufficient to reveal differences of a magnitude several orders less than the levels of the elements being measured; in the second, the problem is to achieve analytical sensitivity sufficient for the detection of very low concentrations. Since the latter difficulty can be reduced by sample preconcentration, and wide variations in the levels of trace elements provide clear evidence of heterogeneity, trace analysis has a strong appeal to those concerned with sea-water characterization.

Methods of preconcentration for use in trace-element analysis of sea water are discussed in this report. It is our intent to examine the subject in the light of our own recent experiences in adapting these methods for spectrometric and polarographic systems of analysis, rather than to present an exhaustive review. For analysts about to tackle the trace analysis of sea water for the first time, it is our hope that the following comments and suggestions will be of help for evaluating the suitability of preconcentration methods to the analytical systems available to them. Two recent reviews (*25*, *46*) should provide excellent starting points for those wishing more complete lists of references. For those concerned with geochemical processes relating to the trace-element composition of sea water other reports (*21*, *22*, *24*, *28*, *33*, *51*) will also prove useful as a basis for further inquiry.

In seawater, the concentrations of many trace elements of current analytical interest fall within the range 10^{-11} to 10^{-8}, expressed as ratios of weight to volume (grams per milliliter). Sensitivities of analytical systems most likely to be employed for sea-water analysis are such that optimum concentrations of elements (expressed as ratios of weight to weight or weight to volume) in samples presented for analysis are on the order of 10^{-6} to 10^{-4} for emission spectrographic and x-ray fluorescence systems, 10^{-7} to 10^{-5} for molecular absorption, atomic absorption, and flame emission spectrophotometry, 10^{-7} to 10^{-4} for polarographic systems, and 10^{-10} to 10^{-5} for neutron activation methods. Polarographic (*71*) and atomic absorption (*16*) techniques have been reported for the direct analysis of several fourth-period transition metals in sea water. In these techniques, the detection limits have been lowered by about one order of magnitude below those usually claimed for commercially available instruments. The precision of the direct polarographic measurements was not given, but the direct atomic absorption measurements were reproducible to no better than 25%. Except for neutron activation, therefore, samples of sea water usually require preconcentration if the analytical system selected is to be operated within the optimum range for best precision. Even with the very great sensitivity of neutron activation analysis, it has been found useful to preconcentrate samples of sea water by removing the water and irradiating the dried salt.

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In any concentration scheme for sea-water analysis, careful consideration must be given to the efficiency of recovery in the final concentrate of the elements of interest, and to the presence in the final concentrate of matter either added as contamination during the concentration process or carried by the process from the original sample to the concentrate) which might interfere with or bias the analysis.

Removal of Water

Removal of the water permits concentration of a sample of ocean water by a factor of about 30, and therefore will provide a concentrate with many trace elements at levels sufficient for activation analysis. Water may be removed by either evaporation of the liquid or sublimation of the solid.

The advantages of sublimation, described by Schutz and Turekian (*48*), who employed freeze-drying to prepare samples for activation analysis, are freedom from spattering, from possible volatilization of certain trace constituents, and from fractional crystallization which produces an inhomogeneous residue. One drawback to this technique is that large amounts of sodium and chlorine are present in the concentrate. Irradiation of these elements produces radioactive Na^{24} and S^{35}, necessitating a long cooling period and radiochemical separation before analysis.

For multistage concentration, water removal can be of considerable value as the first step in the preparation of samples of sea water for spectrographic, spectrophotometric, and polarographic analyses. To determine iron, Lewis and Goldberg (*38*) evaporated sea water and ashed the salty residues with perchloric acid. Iron was then extracted into a solvent for spectrophotometric measurement. All the iron in the original sample was retained in the first stage concentrate, then converted to a water-soluble form for the solvent-extraction step.

Cocrystallization

A remarkably elegant system of preconcentration of sea water for trace analysis was developed by Weiss and his coworkers (*36*, *64–69*) at the U.S. Naval Radiological Defense Laboratory, San Francisco, Calif. The process, named cocrystallization, is distinguished from the more familiar process of coprecipitation by the direct crystallization, from

Table I. Cocrystallization of Trace Elements from Aqueous Solutions with Organic Reagents

(From Weiss and coworkers)

Reagent	Elements Cocrystallized	% Trace Elements Recovered				Ref.
		From lab. solution	At pH	From sea water	At pH	
α-Benzoinoxime	Mo	99–100	1.8–5.5	99	2	(*67*)
1-Nitroso-2-naphthol	Co	100	1–9	99	8[a]	(*69*)
	U	>95	7	99	7–8	(*68*)
	Fe	99	2–9			(*68*)
	Ce,Zn	>95	7			(*68*)
	Zr	97	5			(*68*)
Thionalide	Ag	100	3.5–7	92	3.5	(*36*)
	In,Hg	98–100	3.5–7			(*36*)
	Au	98	0.7			(*36*)
	Os	100	7			(*36*)
	Ta	98	3.5			(*36*)
2-Mercaptobenzimidazole	Au	99	1	99	1	(*65*)
	Sn	100	5			(*65*)
	Hg,Ag	99	1–5			(*65*)
	Ta	95– 98	1–5			(*65*)
Potassium rhodizonate	Ba	100	5–7	99	7–8[b]	(*64*)
	Pu			100	7–8[b]	(*64*)
	Ra,Sr	100	5–7			(*64*)
Ammonium dipicrylaminate	Cs	≥98	2–5			(*66*)
	Rb	≥95	2–8			(*66*)

[a] Untreated sea water.
[b] 2 volumes of 1.6% K-rhodizonate in distilled water + 1 volume of seawater.

Table II. **Solvent-Extraction Systems of Proved or Possible Use for Concentrating Trace Elements from Sea Water**

Elements Analyzed	Original Sample	Sequestering Agents	Solvent	Method of Analysis	Ref.
Ce	Biol. matter Sea water	Bis(2-ethyl hexyl)-hydrogen phosphate	*n*-Heptane	Radiochemical	*(23)*
Cr^{VI}	Brines	Dithizone	Methyl isobutyl ketone (MIBK)	Atomic absorption	*(14)*
Cu	Sea water	Dithizone	CCl_4	Polarographic	*(61)*
Cu	Sea water	Sodium diethyldithiocarbamate (DEDC)	CCl_4	Spectrophotometric	*(56)*
Cu	Sea water	2,2′-Diquinolyl neocuproine	*n*-Hexanol	Spectrophotometric	*(39)*
Cu	Many trace metals		Isobutyl alcohol	Spectrophotometric	*(50)*
Fe	Many trace metals	Diphenylphenanthroline	Isobutyl alcohol	Spectrophotometric	*(50)*
Mn^{II}	Many trace metals	2-Thenoyltriflouroacetone (TTA)	Acetone-benzene	Spectrophotometric	*(13)*
Mn	Sea water	1-Nitroso-2-naphthol	$CHCl_3$	Spectrophotometric	*(39)*
Mo	Radionuclide mixture	α-Benzoinoxime	$CHCl_3$	Radiochemical	*(72)*
Mo	Brines	Dithiol	MIBK	Atomic absorption	*(14)*
Mo		2-Amino-4-chlorobenzenethiol hydrochloride	$CHCl_3$	Spectrophotometric	*(31)*
Ni	Many trace metals	Dimethylglyoxime	$CHCl_3$	Spectrophotometric	*(50)*
Pb	Environmental samples	NaI, dithizone	Isopropyl methyl ketone	Radiochemical	*(57)*
Pb	Sea water	Diethylammonium diethyldithiocarbamate	$CHCl_3$	Spectrophotometric	*(39)*
Pb	Many trace metals	Dithizone	$CHCl_3$	Spectrophotometric	*(50)*
Tl^{III}	Biological samples	NH_2SO_4 and rhodamine-B	Benzene	Spectrophotometric	*(43)*
W	Steels	8-Quinolinol	$CHCl_3$	Spectrophotometric	*(15)*
V	Many trace metals	Phosphotungstate	Isobutyl alcohol	Spectrophotometric	*(50)*
Zn	Rocks	Dithizone	$CHCl_3$	Spectrophotometric	*(27)*
Zn	Urine	Dithizone	CCl_4	Spectrophotometric	*(30)*
Co,Ni	Natural waters	Ammonium pyrrolidine dithiocarbamate (APDC)	MIBK	Atomic absorption	*(11)*
Co,Zn	Sea water	Dithizone	CCl_4	Spectrophotometric	*(19)*
Fe,Mn	Sea water	DEDC	MIBK	Atomic absorption	*(29)*
Al,Cu,Fe	Alloys	Trifluoroacetyl acetone	$CHCl_3$	Gas-liquid Chromatography	*(49)*
Cu,Mo,Zn	Sea water	8-Quinolinol	$CHCl_3$	Spectrochemical	*(7)*
Cu,Mo,Mn,V	Brines	APDC	MIBK	Atomic absorption	(41)
Cu,Fe,Mn,Ni	Brines	Cupferron	MIBK	Atomic absorption	*(14)*
Fe,Mn,Mo, Zn	Milk	APDC	$CHCl_3$	Emission spectrographic	*(63)*
Cu,Co,Ni, Pb,Zn	Tungsten	Dithizone	$CHCl_3$	X-ray spectrographic	*(26)*
Ag,Cu,Fe, Mo,Ni,V	Sea water	DEDC	$CHCl_3$	Emission spectrographic	*(73)*

Table III. Efficiency of Coprecipitation of Elements from Sea Water, Measured by Atomic Absorption Spectrophotometry

	Mn	Fe	Ni	Co	Cu	Zn
Internal std., mg./liter	5	10	5	5	5	1.25
Absorbance						
Before precipitation	0.101	0.070	0.126	0.105	0.165	0.163
	0.097	0.069	0.121	0.106	0.170	0.171
	0.099	0.069	0.113	0.104	0.166	0.161
	0.098	0.069	0.117	0.102	0.170	0.170
Av.	0.099	0.069	0.119	0.104	0.168	0.166
After precipitation	0.001	−0.002	−0.001	0.002	0.001	0.002
	0.000	0.001	0.001	0.000	0.001	0.003
	−0.001	0.000	0.003	0.000	0.001	0.001
	0.001	0.000	0.003	0.001	0.000	0.001
Av.	0.000	0.000	0.002	0.001	0.001	0.002
% coprecipitated	100.0	100.0	98.3	99.0	99.4	98.8

Metals added to acidified sea water; solution neutralized (pH 6 to 7); 50 ml. of 0.2*N* KOH added per liter.

aqueous solution, of an organic reagent which combines with the trace element of interest. The system does not require additional carrier, as is usual with the coprecipitation of a microconstituent, and is based on the principle that if a trace element and an organic reagent combine to form a compound less soluble than the reagent, then the crystallized reagent should be enriched with the trace element (*17*). In the applications to sea-water analysis described by Weiss and his coworkers, organic reagents were used which are insoluble or only sparingly soluble in water, and which form water-insoluble compounds with the trace metals of interest. They were usually added to sea water as solutions of water-miscible organic solvents, after which the mixture was evaporated to the original volume. The crystals which formed were enriched with trace elements and were large enough to be collected by rapid filtration through sintered glass. Data on quantitative recoveries of trace elements from aqueous solutions prepared in the laboratory and from sea water, at hydrogen ion concentrations practical for work with sea water, have been condensed from the papers of Weiss and his coworkers in Table I. In their work, recoveries were determined by radioactive tracers. The organic collectors used for preconcentration were not sufficiently specific for spectrophotometric measurements. Separation from interfering elements collected on the crystals required ashing, redissolution, and separation of the metallic constituents by ion exchange. Suitability of this technique for routine use aboard ships at sea was therefore limited.

The characteristics of atomic absorption spectrophotometry, recently developed as a tool for trace metal analysis, suggest that a single-stage concentration by cocrystallization may be feasible. Atomic absorption techniques are highly specific, being virtually free of spectral interferences, and chemical interferences may be frequently reduced to insignificance if reasonable care is taken with sample preparation and instrumental technique. With the atomic absorption spectrophotometers now on the market, it has been demonstrated that alcohols, ketones, and esters provide satisfactory sample matrices for the analysis of many of the transition elements (*1*). Since many of the organic reagents used for concentrating trace elements by cocrystallization dissolve readily in these solvents, it appears likely that the crystallized organic concentrate could be taken up directly and analyzed without further handling or processing—eliminating tedious separation steps and the associated risks of analytical error.

In applying this technique, the analyst should be aware that in sea water the existence of different chemical species of the elements of interest may reduce the recovery of a significant portion of the total amount in the sample.

Coprecipitation

Coprecipitation techniques have long been favored for the concentration of trace elements from sea water. Ferric hydroxide is the most commonly used carrier. Ferric salts are hydrolyzed upon addition to sea water, forming a negatively charged colloid which serves as an effective scavenger for many trace elements; it coagulates quickly and may be easily separated from the aqueous phase as a solid concentrate enriched with trace metals. The disadvantages of ferric hydroxide coprecipitation lie in the introduction of a large

Table IV. Efficiency of Coprecipitation of Elements from Sea Water, Measured by Radioactive Tracers

	Mn^{54}	Co^{58}	Zn^{65}
Internal standard, counts/min.	2260 ± 90	1170 ± 90	2730 ± 200
Recovered in precipitate	2300 ± 90	1140 ± 90	2610 ± 200
% coprecipitated	102 ± 4	97 ± 8	96 ± 7

Tracers added to acidified sea water; solution neutralized (pH 6 to 7); 50 ml. of 0.2*N* KOH added per liter.

Table V. Efficiency of Coprecipitation of Elements from Sea Water Measured by Polarography

	Cu	Zn	Pb
Internal standard, mg./liter	3.81	3.92	12.43
Concentration after precipitation	0.11	0.31	0.64
	0.16	0.28	0.60
	0.11	0.35	0.46
	0.08	0.33	0.75
Av.	0.12	0.32	0.61
% coprecipitated	96.7	91.8	95.1

Measured by Anodic Stripping Voltammetry

	Cu	Zn	Pb
Initial concentration, μg./liter	1.52	1.83	3.73
Concentration after precipitation	0.15	0.20	0.04
	0.12	0.09	0.60
	0.08	0.12	0.29
	0.17	0.28	0.29
	0.06	0.15	0.41
Av.	0.12	0.17	0.33
% coprecipitated	92.1	90.7	91.1

quantity of iron into the sample with the attendant difficulties of heavy-metal contamination from the reagent and of removing the excess iron prior to analysis. Hydrated oxides of aluminum, rare earths, and manganese also have been used as carriers, but these are subject to the same kinds of disadvantages.

For the activation analysis of Mn and Zn, Rona *et al.* (*47*) coprecipitated these elements from sea water with ferric hydroxide. The pretreatment prior to activation involved a double reprecipitation to remove occluded major ions, and extraction with isopropyl ether to remove iron. They regarded Mn and Zn separated in this manner as "total" in contrast to "divalent" ionic species separated by solvent extraction.

For the colorimetric determination of manganese, iron, and copper from sea water, Skopinstev and Popova (*52*) concentrated their samples by coprecipitation with mercurous sulfide. The mercury was easily removed by ignition of the precipitate at 450° C.

Following the lead of Koroleff (*32*) who determined manganese, Laevastu and Thompson used the natural collectors present in sea water for the coprecipitation of nickel (*35*) and cobalt (*60*). When the pH of a sample of sea water is raised to about 12, the alkaline earth hydroxides and carbonates which are precipitated are effective scavengers for many heavy metals. Koroleff used potassium hydroxide, and Laevastu and Thompson preferred sodium carbonate for raising the pH of the sample. The precipitates were redissolved in acid, and the metals of interest were determined colorimetrically after separation from interfering substances carried down with the precipitate. Loveridge *et al.* (*39*) criticized the method for use in the determination of manganese because of difficulty in handling the bulk of precipitate obtained with large samples. However, in our experience, quantitative recovery of six transition elements from sea water does not require precipitation of all of the magnesium in the sample for the carrier phase; and 10 mg. of precipitate per liter of sea water is sufficient.

A procedure for separating Co, Ni, Mo, Fe, Pb, Sn, Zn, V, Ti, Cr, and Ag from phosphates, alkalies, and alkaline earth metals in plant materials and soils and concentrating them for spectrographic analysis was developed by Mitchell and Scott (*44*). The trace elements were coprecipitated with a mixture of 8-quinolinol, tannic acid, and thionalide. Aluminum and iron were added as carriers. Black and Mitchell (*6*) applied this technique to the spectrographic determination of trace elements in sea weeds and sea water.

Solvent Extraction

Solvent extraction systems have been widely used for concentrating trace elements from sea water. With the proper choice of reagents, an extraction may be selective for either a narrow or a broad range of elements to be transferred from sea water to a solvent concentrate suitable for the analytical system to be used.

A selection of solvent-extraction systems, which either have been, or could be, used for sea water analysis is presented in Table II. In some systems, the extractions are sufficiently specific for the separation of an element for determination by a nonselective analytical system. In others, groups of elements are extracted for simultaneous or successive determinations by more selective analytical systems.

The separation of inorganic ions from aqueous media by phase-distribution procedures has been considered by West (*70*). By selection of appropriate ion-association and chelate solvent systems, almost all of the elements may be extracted from aqueous solutions.

The applicability of a solvent extraction technique to a given analytical system will depend on the properties of the trace element-reagent association and of the solvent. The absorption spectrum of an ion-association compound, complex, or chelate of a metal can often be used for spectrophotometric determination if the solvent does not absorb strongly at the selected wavelength. Combustion properties and viscosity must be considered in choosing solvents for use in emission and atomic absorption systems in which flames carry the sample into the optical path.

Systems in which sequestered trace elements are extracted

Table VI. Efficiency of Extraction of Elements as Diethyldithiocarbamates from Aqueous Solution into Methyl Isobutyl Ketone
(Measured by atomic absorption)

	Mn	Fe	Ni	Co	Cu	Zn
Internal std., mg./liter	5	10	5	5	5	1.25
Absorbance						
Before extraction	0.195	0.153	0.114	0.115	0.216	0.245
	0.195	0.152	0.110	0.117	0.212	0.235
	0.193	0.155	0.111	0.117	0.220	0.247
	0.199	0.155	0.114	0.124	0.211	0.247
Av.	0.195	0.154	0.112	0.118	0.215	0.244
After extraction	0.001	−0.001	0.001	0.000	0.000	−0.002
	0.002	0.000	0.001	−0.002	0.000	−0.002
	0.001	0.000	0.001	0.000	0.001	−0.005
	0.001	−0.001	0.000	−0.001	0.000	−0.006
Av.	0.001	−0.001	0.001	−0.001	0.000	−0.004
% extracted	99.5	100.6	99.1	100.8	100.0	101.6

Metals added to acidified solution; pH adjusted to 6, concentration of DEDC to 0.25%; extracted for 1 minute with MIBK (10 to 1 aqueous to organic).

into chloroform have been widely used. Chloroform solutions can easily be evaporated to adjust the volume of the concentrate to the capacity of spectrophotometer cells, to deposit residues on spectrographic electrodes or planchets used for x-ray and nuclear irradiation and detection, and to provide a solid residue for ashing and redissolution in aqueous media for analysis by electroanalytical or other methods.

Substituted dithiocarbamates appear to be particularly useful for the separation of heavy metals in natural waters. Malissa and Schöffmann (*40*) have studied the color, sensitivity, and selectivity of the reaction products of 30 metal ions with various dithiocarbamates. Lakanen (*37*) extracted 18 trace elements into chloroform with pyrrolidine dithiocarbamic acid and analyzed the evaporated residues by emission spectroscopy. Slavin (*53*), who recently summarized the available data on the use of ammonium pyrrolidine dithiocarbamate (APDC) for the extraction of many heavy metals, cited references for Cu and Zn in fertilizers, plants, and soils; for Pb, Bi, Hg, Ni, and Sb in urine; for Cu, Pb, Cd, Fe, Mn, Co, and Ni in brines; and for Cu in milk and silicate rocks.

Countercurrent and continuous-extraction processes have promise for application to sea water. A true countercurrent extraction apparatus employing compact cells and capable of continuous, large scale operation is under development by Penniston and Johnson (*45*). Brooks (*8*) has reported a system for extracting and separating trace elements from silicate rocks. His liquid-liquid discontinuous countercurrent extractor separated 17 elements, including some only weakly extracted by ordinary methods. The separation of different oxidation states of the same metal was noted. In another application of this procedure (*9*), he used countercurrent extraction for concentrating Mn, Pb, Mo, Sn, Ni, Al, V, and Ag from sea water into a solution of oxine in chloroform. An enrichment factor of 400,000 was obtained and many of the elements could be determined easily by emission spectroscopy.

Two-Stage Concentration

If the analytical system employed for a particular analysis is sufficiently specific, the technique used for concentrating the samples need not be highly selective. Indeed, for multielement analyses, it is desirable to use methods of concentration that will separate large groups of trace elements from the original sample.

For use aboard ships at sea, we have developed a technique to produce a concentrate which can be processed readily for either atomic absorption or polarographic analysis. Trace elements are initially coprecipitated by adding 50 ml. of 0.2*N* KOH or 5% Na_2CO_3 per liter of sea water to samples ranging in volume from 4 to 50 liters. After stirring for 1 hour and settling overnight, the precipitate is collected on a fine-porosity, sintered-glass filter and redissolved in acid. At this point, the concentrate may either be stored in polyethylene bottles or processed further, if analysis is to be performed aboard ship. For a second stage of concentration, the pH of the concentrate is adjusted to 6.0 and enough 5% sodium diethyldithiocarbamate (DEDC) added to make a 0.25% solution. Heavy-metal dithiocarbamates are transferred to an organic phase consisting of methyl isobutyl ketone (MIBK) by a single extraction at a 10 to 1 aqueous to organic ratio. At this stage, the concentrate may be used without further treatment for atomic absorption measurements, as the MIBK provides an excellent matrix for flame analysis. Addition of 1 part of acetone to 5 parts of the concentrate absorbs water droplets entrained in the organic phase. For polarographic measurements, the solvent (amyl alcohol) is evaporated under vacuum; the residue is wet-ashed, converted to the chloride form, and redissolved in distilled water. With this technique, 1000-fold concentration was achieved with the concentrate in a form suitable for conventional polarographic measurement of Cu, Pb, Zn, Fe, and Mn.

Recoveries of trace elements obtained with each of the two steps of the concentration procedure were determined by radiometric, atomic absorption, conventional polarographic, and anodic stripping analyses (Tables III to VI). The use of anodic stripping voltammetry for trace analysis of brines (*2*) opens a promising avenue of approach to the analysis of sea waters. The measurements shown in Table V (lower) were made on raw sea water taken from a depth of 20 meters from Sooke Inlet on the west coast of Vancouver Island, Canada, which because of industrial pollution is not necessarily representative of open ocean water.

Sorption

Sorption methods have long been used for the removal of substances from dilute solutions and, with the advent of radioactive isotopes, have been invaluable for concentration and separation of radioactive mixtures by column chromatography. Chromatographic techniques for the isolation of fission products and other radioactive substances from natural waters have been widely reported in the literature of radiochemistry and need not be repeated here. Several new techniques involving sorption phenomena currently being developed, however, show much promise of usefulness for trace metal characterization of sea waters.

Carritt (*12*) has proposed and tested a chromatographic procedure for concentrating heavy-metal ions from sea water. A strongly basic anion-exchange resin is charged with dithizone in basic solution and packed into a column. Sea water is then passed through the column, which retains ions of those metals which form metal dithizonates in slightly basic solution. The drawbacks to this technique are: To ensure quantitative recovery of the largest number of dithizone-reacting metals, a slow rate of flow is required which extends the time for processing large samples; a large quantity of concentrated acid is required to elute the absorbed metals from the column; and it shares with all other concentration schemes which employ binding of ions in sea water by sequestering agents, the disadvantage that competition by natural sequestering agents in sea water may affect the recovery of the ions in question.

More recently, Bauman (*3*) has developed a technique for preparing a dithizone-coupled cellulose column for which he claims substantial reduction in the first two disadvantages listed above.

Although the cation-exchange properties of the ammonium salts of some heteropoly acids have been known for over 50 years (*4*, *10*, *20*, *42*, *58*, *59*), it has been only recently that microcrystalline aggregates of these inorganic salts have been used for the selective adsorption of alkali, alkaline earth, and some transition metals (*34*). The use of ammonium molybdophosphate (AMP) crystals for the separation of alkali metals has been described by Smit *et al.* (*54*, *55*) and in recent United Kingdom Atomic Energy Agency reports (*62*).

In our laboratories, preliminary experiments with batch methods effected quantitative transfer of rubidium and cesium from solution in 1 liter of acidified sea water (pH 2) to 1 gram of AMP microcrystals. Recovery was determined by radiometric measurement of Cs^{137}, and atomic absorption measurement of stable Rb added as internal standards.

For reasonably precise ($<5\%$) flame emission or atomic absorption measurements of Rb and Cs, solutions containing 5 to 50 p.p.m. of each are recommended (*5*, *18*). Batch treatment of 1 liter of sea water with AMP should be sufficient to produce a 10-ml. concentrate containing about 12 p.p.m. of Rb, but 40 liters of sea water would be necessary to provide enough Cs for a 10-ml. concentrate of about 8 p.p.m. Rb, and Cs adsorbed on AMP can be eluted with NH$_4$NO$_3$ or the crystals can be dissolved with dilute NH$_4$OH to provide the liquid concentrate.

Summary

Although several analytical systems of great sensitivity have been applied to the direct analysis of sea water, adequate precision and accuracy for reliable trace characterization can best be achieved by concentration before analysis.

Complete recovery, in a concentrate of a heavy metal trace element, whatever its physically or chemically combined state in sea water, can usually be obtained by removal of the water from the sample. Selective coprecipitation permits much greater concentration factors and quantitative recovery of many trace elements as well as separation from the major salts. Care must be taken to avoid introduction of contamination with the reagents added to effect the precipitation. Trace elements in the ionic state in sea water may be concentrated by cocrystallization and solvent extraction procedures involving the use of organic sequestering agents.

We have found that two-stage preconcentration, by coprecipitation and solvent extraction, is useful for preparation of sea-water samples for atomic absorption and polarographic analyses. Alcohol, ketones, and esters make effective matrices for the analysis of concentrates by atomic absorption.

Heavy alkali-metal ions may be adsorbed onto ammonium molybdophosphate microcrystals to separate them from the major salts of sea water and to provide concentrates suitable for determination of both radioactive and stable species.

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Received for review February 17, 1967. Accepted May 8, 1967. Work supported by the Bureau of Commercial Fisheries Biological Laboratory, Seattle, Wash.; the Department of Oceanography, University of Washington, Seattle (Contribution 408) under Contract NONR-477(37) Project NR 083-012 Office of Naval Research; and the Laboratory of Radiation Biology, University of Washington, Seattle, under Contract AT(45-1) 1385, U.S. Atomic Energy Commission. It was the subject of contributed paper number 83 at the Symposium on Trace Characterization Chemical and Physical, conducted by the National Bureau of Standards, Gaithersburg, Md., October 3 to 7, 1966. Reference to the work of Cyrus Feldman and T. C. Rains on the collection and flame photometric determination of cesium [Anal Chem. 36, 405–9 (1964)] was inadvertently omitted from the section on sorption and from Literature Cited.

Reprinted from Sharks, Skates, and Rays. The Johns Hopkins Press, Baltimore, Md., 1967

6

SHARK TAGGING IN THE EASTERN PACIFIC OCEAN, 1962–65

Susumu Kato and Anatolio Hernandez Carvallo

This paper provides data on the movements and growth of several species of sharks from the eastern tropical Pacific Ocean and on the suitability of various types of tags. The data came from recaptures of sharks tagged by the Bureau of Commercial Fisheries Tuna Resources Laboratory, La Jolla, California, during 1962–65. Tagging was greatest in 1964, when the work was supported by a grant from the Office of Naval Research to the American Institute of Biological Sciences. Work under this grant was conducted jointly by the Bureau of Commercial Fisheries Tuna Resources Laboratory and the Instituto Nacional de Investigaciones Biologico-Pesqueras, Mexico.

Because only a year has elapsed since the majority of sharks were tagged, only preliminary data are presented.

SPECIES AND STUDY AREAS

Sharks from three different habitats were tagged: offshore, from California to Peru; coastal, within and near the Gulf of California; and insular, at the Revillagigedo Islands. The species tagged and references which give their descriptions are listed in Table 6–1.

Five major shark-fishing centers, San Jose del Cabo, Mazatlan, Isla Maria Madre, Isla Isabela, and San Blas, are within or closely adjacent to the coastal tagging area. Sharks are fished by longline, handline, gillnet, and beach seine; shrimp trawlers also contribute to the catch. These sharks are used principally as bacalao (salted and dried flesh), although some

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This work was supported by contract Nonr 4526(01) NR 104-832. We are indebted to Stewart Springer for his valuable advice, support, and encouragement. John Prescott and the late David Davies helped in preliminary studies on the suitability of different tags. The owners and captains of American and Mexican vessels allowed us to tag sharks during fishing cruises. Lee Palm permitted us to accompany one of his regular sport-fishing trips to Socorro Island on *Red Rooster*. He and the crew of the vessel have been of continuing aid throughout the study. Almirante Antonio Vasquez del Mercado, former Director of the Mexican Direccion General de Pesca, and Rodolfo Ramirez, Mauro Cardenas, and Hector Chapa aided by committing their agencies to cooperate in the study. Adolfo Torres May and Victor Tejeda of the government's shark-processing plant at Isla Maria Madre provided valuable information, as did Hector Ferreira. Advertisement of the tagging program was aided by members of the Inter-American Tropical Tuna Commission and California Department of Fish and Game.

TABLE 6–1. Species of sharks tagged.

Species	Reference
1. *Alopias vulpinus*	Bigelow and Schroeder, 1948
2. *Carcharhinus albimarginatus*[2]	Garrick and Schultz, 1963
3. *C. altimus*	Kato, 1964
4. *C. falciformis*[2]	Garrick et al., 1964
5. *C. galapagensis*	Rosenblatt and Baldwin, 1958
6. *C. limbatus*	Rosenblatt and Baldwin, 1958
7. *C. longimanus*	Bigelow and Schroeder, 1948
8. *C. porosus*	Rosenblatt and Baldwin, 1958
9. *C. velox*	Rosenblatt and Baldwin, 1958
10. *Prionace glauca*	Bigelow and Schroeder, 1948
11. *Rhizoprionodon longurio*	Springer, 1964
12. "Cazon" (=*R. longurio?*)	
13. *Ginglymostoma cirratum*	Bigelow and Schroeder, 1948
14. *Mustelus* sp.	
15. *Sphyrna lewini*	Garrick and Schultz, 1963
16. *S. zygaena*	Garrick and Schultz, 1963

[2] According to J. A. F. Garrick (personal communication) *C. albimarginatus* and *C. falciformis* are conspecific with *C. platyrhynchus* and *C. malpeloensis*, respectively.

small ones are sold fresh. The hides, livers, and fins of most large sharks are also sold. At least 19 species of sharks are found in this area (Kato, 1965), but the most common are *Carcharhinus limbatus*, *C. porosus*, *Rhizoprionodon longurio*, several species of *Sphyrna*, and one or two species of *Mustelus*. The ocean near the continental shore has a gently sloping mud bottom.

The insular tagging areas included Socorro Island and San Benedicto Island of the Revillagigedo Islands. The two islands are located about 250 miles south of the tip of Baja California. Unlike the nearly flat bottom of the Mexican coast, the sea floor around the islands is composed of volcanic rock and coral, with steep slopes, seamounts, and shallow banks. At least eight species of large sharks occur near the islands, but the dominant forms are juveniles of *Carcharhinus albimarginatus* and *C. galapagensis*. Fishing at the islands is limited to sailors stationed on Socorro Island, a few itinerant fishermen from the Mexican mainland, and United States tuna fishermen. Exploratory fishing vessels of the Mexican government and an American sport-fishing vessel, *Red Rooster*, also fish infrequently at the islands.

A third island in this group, Roca Partida, lies 65 miles west of Socorro Island. Since its shark fauna is different from that of the other islands, however, it is included in the offshore area.

The offshore area includes all offshore waters between southern California and Peru in addition to Roca Partida. The area coincides with fishing grounds for skipjack, *Katsuwonus pelamis*, and yellowfin, *Thunnus albacares*, tuna in the eastern Pacific; most sharks were tagged on United

States purse seine vessels. Although several sharks are caught by these vessels, *Carcharhinus falciformis* is by far the dominant species occurring with tuna (Kato, 1964). Returns of sharks tagged offshore are expected from American and Mexican tuna vessels, Japanese longline vessels, and a high-seas longline shark fishery of the Tres Marias Islands.

MATERIALS AND METHODS

Tagging was conducted from tuna purse seine vessels, shrimp trawlers, sport-fishing vessels, and research vessels (Table 6–2). Shark tagging was not the principal objective of most of the cruises but was incidental to other operations. On the other hand, the sole objective of the cruises of the *Yaqui Queen* and *Red Rooster* in 1964 was to tag sharks. The gear and methods used during these cruises are described below.

Sharks were caught principally with handlines and rod and reel on small barbless hooks. Anchored setlines with barbed hooks buoyed off the bottom also had some success. Small sharks were lifted aboard with a dipnet and placed on a foam-rubber cushion, where they were tagged and measured. Large sharks were landed by a brail 5 feet (1.5 m) in diameter, in conjunction with an electric hoist mounted on an overhead monorail. The

TABLE 6–2. Summary of data on shark tagging, eastern Pacific Ocean, 1962–65.

Tagging date	Cruise	Locality	Tag type	No. tagged	Method of capture
1962					
1. March	*Royal Pacific*	Guatemala; Colombia	Strap	69	Purse seine
2. April	*Royal Pacific*	Nicaragua	Strap	3	Purse seine
3. July	*Royal Pacific*	Ecuador	Strap	1	Purse seine
4. August	*West Point*	Revillagigedo Islands	Strap	90	Purse seine, handline
1963					
5. January	*Royal Pacific*	Peru; Colombia	Strap	19	Purse seine
6. August	*Elsie A.*	Central Baja California	Strap Dart	8	Purse seine
1964					
7. July	*Yaqui Queen* (chartered)	Revillagigedo Islands	Strap Petersen Dart	47	Handline, longline
8. November	*Cerralvo*	Mexican coast (Altamura)	Strap Petersen	2	Shrimp trawl
9. November	*Red Rooster* (chartered)	Mexican coast (Altata to San Blas); Revillagigedo Islands	Strap Rototag Petersen Dart	545	Handline, longline, rod and reel
1965					
10. May	*Red Rooster*	Socorro Island; Cape San Lucas	Strap Rototag	60	Handline, rod and reel
11. May	Shrimp trawler	Mexican coast (Altata)	Strap	2	Trawl
12. June	*Scofield* (research vessel)	Southern California	Strap	4	Handline
13. July	*Elsinore*	Ecuador	Strap	5	Purse seine
14. August	*Independence*	Ecuador	Strap	5	Purse seine

shark was retained in the net on deck during tagging. Body length (tip of snout to precaudal pit or base of caudal) and total length were measured with a metal tape rule while the head was held immobile with the aid of the iron rim of the brail and the tail was forcibly straightened.

A tag was needed which was conspicuous, would be retained by the shark for long periods with minimum effect on the health and behavior of the shark, and would withstand extended periods in sea water. Four different tags were used to learn which were suitable for tagging sharks (Table 6–3; Fig. 6–1).

In 1962 we used colored discs with strap tags to improve the visibility of the tags; we discontinued their use, however, when we learned that they were quickly shed.

Rototags, strap tags, and Petersen tags were usually attached on the first dorsal fin. Most tags were applied in pairs, consisting of a Petersen tag and either a strap tag or a Rototag. A few Rototags were paired with strap tags. A dart tag was attached to the back of a few large sharks as a third or fourth tag.

A tetracycline antibiotic salve was applied to the tagging wound.

NUMBERS, SIZES, AND SEX RATIOS OF SHARKS TAGGED

A total of 860 sharks of 15 species were tagged (Table 6–4). The 1964 cruises of *Yaqui Queen* and *Red Rooster* accounted for 592 (69 percent) of the total. The localities of tagging extended from southern California to northern Peru (Fig. 6–2).

TABLE 6–3. Description of tags used.

Tag	Material	Size	Color	Lettering	Supplier
Petersen disc[a]	Laminated plastic	1-in diameter	Red with black lettering	One disc: DEVUELVA ESTA MARCA A LA OFICINA DE PESCA ANOTE FECHA Y LUGAR DE CAPTURA RECOMPENSA 15 PESOS Other disc: RETURN TO BUR. COMM. FISHERIES BOX 6317 SAN DIEGO 6	Floy Tag and Manufacturing, Inc.
Jumbo Rototag	Plastic	¾ x 1¾ in; shaft on male half ¼-in diameter	Yellow with black lettering	Male half: DEVUELVA OF. DE PESCA PREMIO 15 PESOS BU COM FISH SAN DIEGO Female half: None	Oberarch Patents (England)
Strap (cattle size ear tag)	Monel metal	⅜ x 1⅝ in; inside space ⅜ in	Metallic	Female side: DEVUELVA OF. DE PESCA CON FECHA Y LUGAR DE CAPTURA. 15 PESOS Male side: RETURN BUR COMM. FISH SAN DIEGO	National Band & Tag Company
Dart	Resinite tubing with hard nylon dart	⅛-in diameter; ½-in long	Yellow with black lettering	RETURN TAG TO AIBS SHARK RESEARCH 2000 P ST. N.W. WASH. D.C. 20036 U.S.A.	Floy Tag and Manufacturing, Inc.

[a] Flat head stainless steel needles (1.5 inches long x 0.035-inch diameter) used with Petersen tags were supplied by John Hassall, Inc.

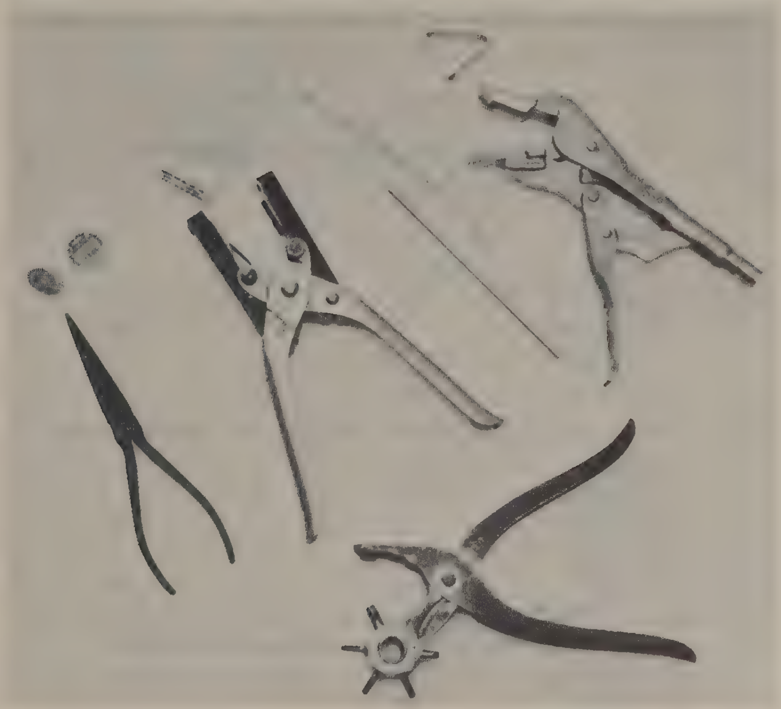

FIG. 6–1 Tags and applicators. *Top, left* to *right:* Petersen disc tag and needle-nose pliers; Jumbo Rototag and applicator; dart tag and applicator; Monel metal strap tag and applicator. *Lower right:* leather punch for use with Rototag.

Two or more tags were applied on 506 sharks (Table 6–5). Most of these (499) were tagged near the Mexican coast or at Socorro Island in 1964.

Some species of sharks in our catch appeared to be sexually segregated at particular times or localities (Table 6–6). Along the Mexican coast, we caught more male than female *Sphyrna lewini* and *Rhizoprionodon longurio;* on one occasion, 40 male *Rhizoprionodon longurio* were captured without a single female. At Socorro Island during one cruise, we caught more female than male *Carcharhinus albimarginatus,* but males outnumbered female *C. galapagensis.* The numbers of males and females were about equal in *C. limbatus, C. porosus,* and *C. falciformis.*

Our fishing methods and choice of fishing areas tended to select smaller individuals (Fig. 6–3). Except for *R. longurio,* no differences in size between sexes were evident; consequently, lengths for both sexes were combined.

TABLE 6–4. Number of sharks tagged by localities and species, and number and percentage recovered.

Species	No. tagged	No. recaptured	Percentage recaptured
Mexican coast: Altata to San Blas; Cabo San Lucas			
C. limbatus	155	19	12
C. porosus	77	6	8
R. longurio	73	2	3
S. lewini	19	1	5
Mustelus sp.	2	—	—
"Cazon"	2	1	50
G. cirratum	1	1	100
C. velox	1	—	—
Total	330	30	9
Revillagigedo Islands: Socorro Island, and San Benedicto Island			
C. galapagensis	209	29	14
C. albimarginatus	138	19	14
C. falciformis	4	1	25
C. limbatus	1	—	—
S. lewini	1	—	—
Total	353	49	14
Offshore: Southern California to Peru; Roca Partida			
C. falciformis	119	4	3
C. limbatus	28	—	—
C. galapagensis	6	—	—
P. glauca	5	—	—
S. lewini	5	—	—
S. zygaena	4	—	—
C. altimus	4	—	—
C. longimanus	3	—	—
A. vulpinus	2	—	—
C. albimarginatus	1	—	—
Total	177	4	2
Grand Total	860	83	10

The length distributions of *C. limbatus* (range 56–88 cm; mean 66) and *C. porosus* (range 48–89 cm; mean 64) were similar; each had a single exaggerated peak which probably represented a single age group. *C. limbatus*, the larger species, attains a body length of about 190 cm; *C. porosus* grows to about 110 cm. Three distinct modes were present in the length distribution of *R. longurio*, a small species with a maximum body length of about 90 cm. The sharks tagged ranged from 35 to 82 cm (mean 64 cm). The smaller-size groups included young males and females, but all sharks in the largest-size group were adult males.

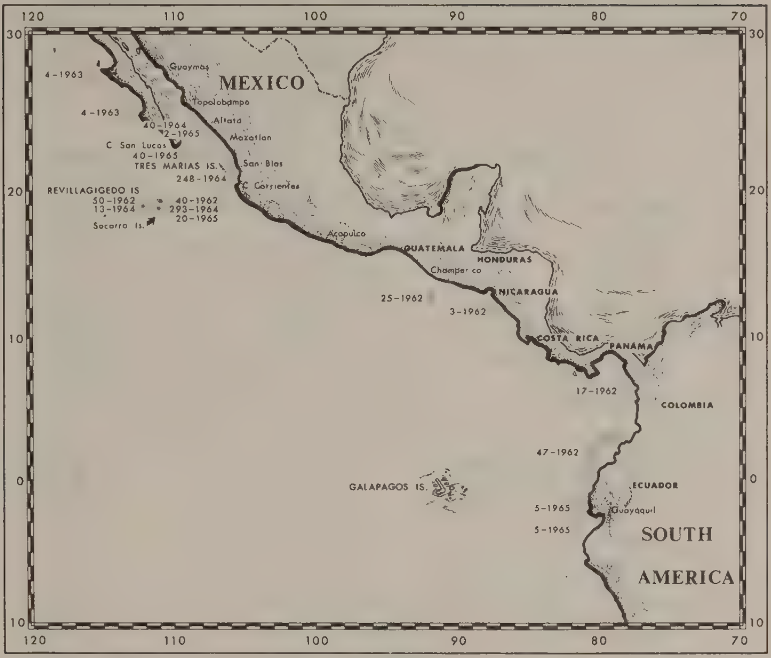
120
110
100
90
80
70
30
20
10
0
10
4-1963
4-1963
40-1964
2-1965
C San Lucas
40-1965
TRES MARIAS IS.
248-1964
REVILLAGIGEDO IS
50-1962
13-1964
40-1962
293-1964
20-1965
Socorro Is.
Guaymas
MEXICO
Topolobampo
Altata
Mazatlan
San Blas
C Corrientes
Acapulco
GUATEMALA
HONDURAS
Champerico
25-1962
3-1962
NICARAGUA
COSTA RICA
PANAMA
17-1962
COLOMBIA
47-1962
GALAPAGOS IS.
ECUADOR
5-1965
5-1965
Guayaquil
SOUTH
AMERICA

FIG. 6–2 Tagging localities (*shaded*), number of sharks tagged, and year of tagging.

Unlike the coastal sharks, both *C. albimarginatus* and *C. galapagensis*, which were tagged at the Revillagigedo Islands, lacked well-defined modes in their length distributions. The range for *C. albimarginatus* was 54 to 163 cm (mean 69 cm), and, for *C. galapagensis*, it was 44 to 136 cm (mean 79 cm). The former grows to about 225 cm in body length, and the latter may attain a length of about 250 cm. Umbilical scars were plainly visible on the smallest individuals of both species.

Measurements of 12 *C. falciformis* ranged from 140 to 165 cm (mean 152 cm). Most unmeasured ones had similar lengths. This species grows to a body length of about 190 cm.

RECOVERIES

By January, 1966, 83 (10 percent) of the 860 tagged sharks had been recaptured (Table 6–4). Tagged sharks were recaptured by shark, tuna, shrimp, and sport fishermen from Mexico, exploratory fishing vessels of the Mexican Government, a Japanese longline fisherman, and United States sport fishermen and commercial tuna fishermen.

TABLE 6–5. Types and numbers of tags used in different localities.

Tag types and combinations	Tagging locality: Mexican coast	Revillagigedo Islands	Offshore	Totals
Single tags				
Petersen	33	11	—	44
Strap	28	53	159	240
Rototag	51	19	—	70
Double tags				
Petersen, strap	110	138	4	252
Petersen, Rototag	106	87	—	193
Strap, Rototag	1	9	—	10
Strap, dart	—	—	5	5
Triple tags				
Petersen, strap, dart	1	6	2	9
Petersen, strap, Rototag	—	16	2	18
Petersen, Rototag, dart	—	2	—	2
Quadruple tags				
Petersen, strap, Rototag, dart	—	12	5	17
Totals	330	353	177	860

TABLE 6–6. Number of males and females tagged, and chi-square values testing deviation from a 1:1 sex ratio.

Species	Cruise	No. of males	No. of females	Chi-square[a]	p
C. limbatus	*Red Rooster,* 1964	74	80	0.23	>0.05
C. porosus	*Red Rooster,* 1964	35	39	0.22	>0.05
S. lewini	*Red Rooster,* 1964	14	5	4.26	<0.05
R. longurio	*Red Rooster,* 1964	23	10	5.12	<0.05
R. longurio	*Red Rooster,* 1965	40	—	8000.00	<0.001
C. albimarginatus	*West Point,* 1962	8	8	0	>0.05
C. albimarginatus	*Yaqui Queen,* 1964	4	2	0.66	>0.05
C. albimarginatus	*Red Rooster,* 1964	42	65	4.94	<0.05
C. albimarginatus	*Red Rooster,* 1965	5	5	0	>0.05
C. galapagensis	*West Point,* 1962	13	9	0.73	>0.05
C. galapagensis	*Yaqui Queen,* 1964	15	17	0.12	>0.05
C. galapagensis	*Red Rooster,* 1964	85	57	5.52	<0.05
C. galapagensis	*Red Rooster,* 1965	5	5	0	>0.05
C. falciformis	All cruises	50	61	1.09	>0.05

[a] Snedecor, 1956.

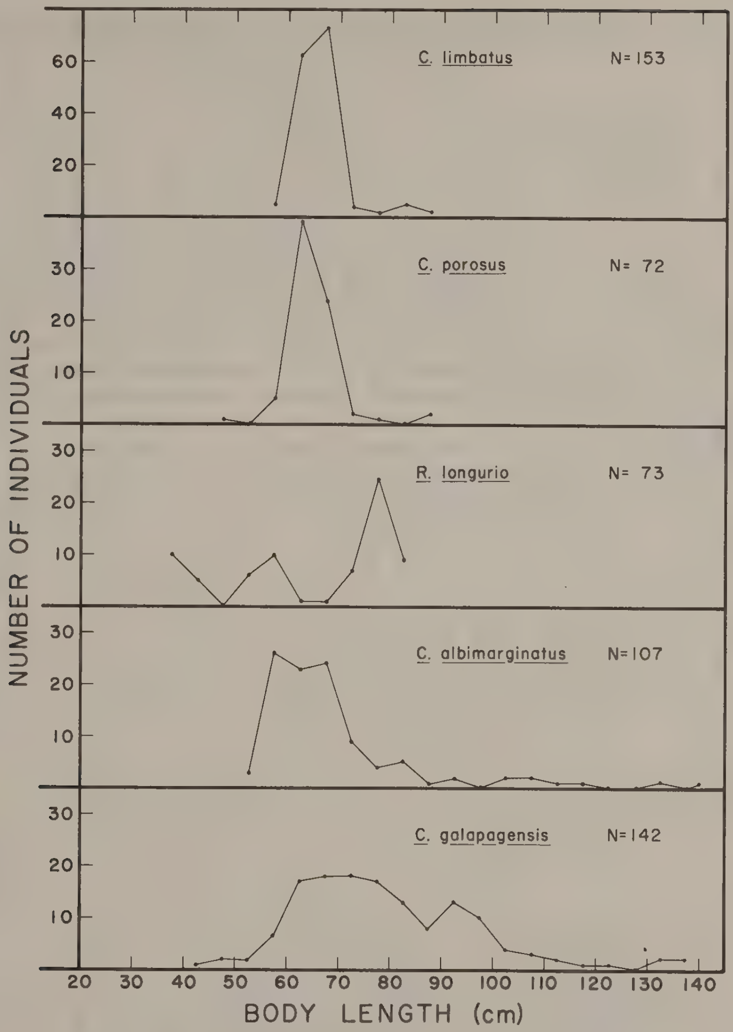

FIG. 6–3 Length-frequency distribution of five species tagged, in 5-cm groups.

Thirty sharks (9 percent of those tagged) were recaptured from the Mexican coast, 49 (14 percent) from the Revillagigedo Islands, and only 4 (2 percent) from the offshore area.

The length of time tagged sharks were at liberty before recapture varied widely for the different tagging localities (Table 6–7). Within the coastal area, the variation was probably due to fluctuations in fishing intensity and movements of sharks away from the fishing grounds. The time at

TABLE 6–7. Number of sharks recaptured after different periods of liberty.

	Months at liberty				
Tagging locality	<1	1–3	3–5	5–7	>7
Mexican coast	3	15	6	4	1
Revillagigedo Islands	1	3	18	17	10
Offshore	1	1	1	1	—

which tagged sharks were recaptured at the Revillagigedo Islands, however, depended primarily upon cruises to this area by Mexican Government fishing vessels, by *Red Rooster*, and by us.

Nearly all sharks tagged at the Revillagigedo Islands were recaptured near the tagging locality (Table 6–8). One *C. galapagensis* tagged at San Benedicto Island, however, traveled 32 miles over deep water to Socorro Island.

Sharks from the coastal and offshore areas, on the other hand, showed considerable movement. Most coastal sharks moved northward from San Blas, where they had been tagged in December. Two *C. limbatus* tagged at Altata in November moved southward, but six tagged at San Blas in December moved northward (Fig. 6–4). One *R. longurio* tagged in May at Cape San Lucas was recaptured 4 months later after it had traveled 600 miles northward on the western side of Baja California.

Four *C. falciformis* were recaptured from the offshore area. Three of them were tagged at Roca Partida; one was recaptured there after 10 weeks, the second traveled 65 miles to Socorro Island where it was recaptured after 4 months, and the third traveled 95 miles to San Benedicto Island in 5 months. The fourth shark was recaptured 50 miles from the tagging locality off Guatemala, 3 or 4 days after it had been tagged.

Most sharks whose life histories have been studied have shown extensive

TABLE 6–8. Number of tagged sharks recovered at different distances from the tagging locality.

	Miles traveled				
Tagging locality, and species	<1	1–5	6–10	11–19	>20
Mexican coast					
C. limbatus	2	1	2	6	8
C. porosus	—	—	1	3	1
R. longurio	2	—	—	—	1
S. lewini	—	—	—	—	1
G. cirratum	—	—	—	—	1
Revillagigedo Islands					
C. albimarginatus	14	5	—	—	—
C. galapagensis	16	7	2	3	1
C. falciformis	—	—	1	—	—
Offshore					
C. falciformis	1	—	—	—	3

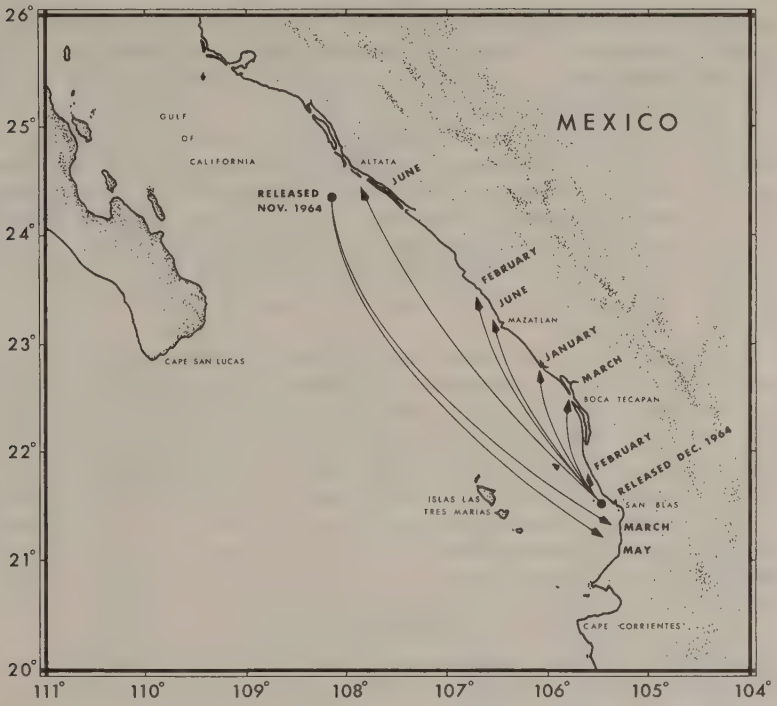
26°
25°
24°
23°
22°
21°
20°
111°
110°
109°
108°
107°
106°
105°
104°
GULF OF CALIFORNIA
MEXICO
ALTATA
JUNE
RELEASED NOV. 1964
FEBRUARY
JUNE
MAZATLAN
JANUARY
MARCH
BOCA TECAPAN
FEBRUARY
RELEASED DEC. 1964
SAN BLAS
MARCH
MAY
ISLAS LAS TRES MARIAS
CAPE SAN LUCAS
CAPE CORRIENTES

FIG. 6–4 Movements of tagged *C. limbatus*.

movement. This was true not only for inshore species like *G. australis* (Olsen, 1954), *S. acanthias* (Holland, 1957), and *E. milberti* (Springer, 1960) but also for pelagic species, e.g., *Prionace glauca* (Suda, 1953). Movements and distribution of sharks are generally related to reproductive activity, seasonal changes in environmental conditions, or both.

Our tag recoveries indicated that young *C. limbatus*, and possibly *C. porosus*, made seasonal north-south migrations within and near the Gulf of California. Oceanographic conditions within the Gulf of California provide clues to the causes of such movements. At Puerto Penasco, near the head of the Gulf, the sea-surface temperature varies from 14.9C in January to 31.2C in August, a range of 16C (Roden, 1964). At Mazatlan, near the mouth of the Gulf, the temperature varies 9C annually, from 21.1C in February to 30.1C in September (Roden, 1964). Just below Cabo Corrientes, which is located slightly south of San Blas, oceanic conditions are more stable; temperatures change only 5C annually, from 25C to 30C (Renner, 1963). Salinity within the Gulf varies only slightly from Puerto Penasco to Mazatlan and shows little seasonal variation (Roden, 1964). Fluctuations in temperature then are probably the chief factors influencing seasonal movements of sharks within the Gulf. Thus we expect *C. limbatus*, which is generally a warm-water species (Bigelow and Schroeder, 1948), to move southward during winter and northward into the Gulf as the waters warm in late spring.

Large *C. limbatus* are scarce in inshore waters except during late spring and early summer, when there is an influx of pregnant females. Adults are taken regularly by purse seine fishermen on the high seas (although always fairly close to shore) and by the shark fishery at Islas Las Tres Marias; they are apparently present throughout the year near Manzanillo, Mexico, which is south of Cabo Corrientes. The distribution and movements of *C. limbatus* are similar in many respects to those found for *C. milberti*, by Springer (1960).

Unlike the Gulf of California, the Revillagigedo Islands provide a stable oceanic environment; temperatures range from 24C in March to a high of about 28C in August (Renner, 1963). Our tag returns indicated that juveniles of both *C. albimarginatus* and *C. galapagensis* were restricted to the shallow water surrounding the islands. Large sharks of both species were also near shore, but they were rarely found with the juveniles. Adults of *C. albimarginatus* appeared to be more abundant than adults of *C. galapagensis*, at least at Socorro Island. On the other hand, more large *C. galapagensis* than *C. albimarginatus* were taken by purse seines in offshore waters, both near the islands and on the high seas (Kato, 1964).

Although juveniles of the two species seemingly occupied the same ecological niche, close examination of the catch data suggested that *C. albimarginatus* was dominant on parts of the eastern shores of Socorro Island, and *C. galapagensis* was more abundant at all other areas fished.

GROWTH OF TAGGED SHARKS

The growth rate of both *C. albimarginatus* and *C. galapagensis* was extremely slow (Table 6–9). We recaptured and measured 17 sharks which we had tagged at Socorro Island about 5½ months previously. Measurements of the longer-term recoveries (9½ and 14 months at liberty, Table 6–9) were made by crew members of *Red Rooster* who used our measuring methods. The growth data on male *C. albimarginatus* were inconsistent; four had negative increments and two grew at a faster rate than all other sharks (possibly we made errors in measuring these two sharks). Our data indicated an average annual increment of 31–54 mm for juvenile *C. albimarginatus* and 41 mm for juvenile *C. galapagensis*.

Little is known about the growth rate of large sharks. Three large *Somniosus microcephalus* tagged by Hansen (1963) grew 10 mm in 2 years, 150 mm in 14 years, and 80 mm in 16 years, an average increment of 7.5 mm per year. Springer (1960) estimated from indirect evidence that *Carcharhinus milberti* grew from about 60 cm at birth to 200 cm in 2 years, an average growth rate of about 700 mm per year.

Holland (1957) reported an average growth increment of 30 mm per

TABLE 6–9. Length increments of tagged sharks recaptured at Socorro Island.

Sex and body length at tagging (mm)	Increase in length at recapture (mm)	Time at liberty (months)	Length increment (mm/year)
	C. albimarginatus		
Female			
555	20	5.5	47
565	0	5.5	—
650	20	5.5	47
680	20	5.5	47
755	15	5.0	39
1,050	5	9.5	6
			Average 31
Male			
605	−10	5.5	—
665	10	5.5	23
665	35	5.5	83
685	135	14.0	116
690	−5	5.5	—
690	80	5.0	208
710	−5	5.5	—
1,135	−15	5.5	—
			Average 54
	C. galapagensis		
Female			
495	15	5.5	33
Male			
640	10	9.5	13
740	25	5.5	59
780	70	9.5	88
865	10	5.5	23
880	70	14.0	60
905	35	14.0	30
955	5	5.5	12
970	95	14.0	81
1,110	−5	5.0	—
			Average 41

year from tagging studies of *Squalus acanthias*, a small species. Olsen (1954), in studies of the larger *Galeorhinus australis*, used length-frequency and tagging data to calculate average annual length increments for different age groups that ranged from 130 mm for 1-year-old sharks to 30 mm for 12-year-old sharks.

SHEDDING RATES AND CONDITION OF TAGS AND TAG WOUNDS

Returns from multiple-tagged sharks indicated that Petersen and dart tags were shed at much higher rates than Rototags and strap tags (Table 6–10). Because of the high shedding rate of Petersen tags, it is difficult to

TABLE 6–10. Shedding rates of tags, from recaptures of 70 multiple-tagged sharks.[a]

Locality and tag type	No. of tags attached	No. of tags shed	Percentage shed
Mexican coast			
Petersen	25	20	80
Rototag	8	0	0
Strap	18	1	6
Revillagigedo Islands			
Petersen	42	21	50
Rototag	21	2	10
Strap	28	1	4
Dart	2	2	100
Offshore			
Petersen	1	1	100
Rototag	1	0	0
Strap	1	0	0
Dart	1	1	100
Totals			
Petersen	68	42	62
Rototag	30	2	7
Strap	47	2	4
Dart	3	3	100

[a] The 70 sharks included 64 with 2 tags, 4 with 3 tags, and 2 with 4 tags.

assess the loss of rototags and strap tags; most double tags consisted of a Petersen tag paired with a rototag or strap tag (Table 6–5). Our data are inadequate for estimating the probabilities of loss of both tags. Consequently, the shedding rates given here are minimal.

The percentages of strap tags and Rototags returned from the Revillagigedo Islands were equal, but at the Mexican coast the percentage of Rototags recovered was only one-half that of strap tags (Table 6–11). Recoveries of Petersen tags were also fewer in proportion to recoveries of strap tags from the Mexican coast. These differences may be due to species

TABLE 6–11. Comparison of recovery rates of sharks from the Mexican coast and Revillagigedo Islands, after tagging during the 1964 *Red Rooster* cruise.

Locality and tag type	No. of tags released	No. of tags recovered	Percentage recovered
Mexican coast			
Petersen	248	5	2.0
Rototag	129	9	7.0
Strap	126	19	15.1
Revillagigedo Islands			
Petersen	231	17	7.4
Rototag	131	21	16.0
Strap	139	22	15.8

differences or to incomplete reporting of recaptured sharks. We consider the recovery rates from the Revillagigedo Islands reliable because nearly all the recaptures were made by us, by fishery vessels of the Mexican Government, or by crew members of *Red Rooster*.

The percentages of Petersen tags that were shed ranged from 50 (Revillagigedo Islands) to 80 (Mexican coast). We examined the fins of 20 multiple-tagged sharks that had shed their Petersen tags after they had been at liberty from 11 to 34 weeks (average 20 weeks). In most fins, we saw a dark line caused by the pin as it cut through the fin. The original tag wound had healed completely, but in a few sharks the trailing edge of the dorsal fin was still split. In 14 sharks which had retained their tags from 8 to 28 weeks (average 17 weeks), the tag wounds were swollen and the skin under the discs was abraded. Neither the stainless-steel pins nor the plastic discs showed any deterioration after 1–28 weeks (average 14 weeks) at sea. Some discs had organisms attached, but the lettering was unaffected.

The high shedding rate of Petersen tags—50 percent or more in 6 months—leads us to conclude that these tags are unsuitable for the species studied. Olsen (1953) double-tagged *Galeorhinus australis* with Petersen and Nesbit internal tags and found a similar 50-percent loss of Petersen tags. Hansen (1963) obtained a return of 6.8 percent when he tagged 411 *Somniosus microcephalus* with Petersen tags. Holland (1957) recovered a similar 6.7 percent of 9,705 tagged *Squalus acanthias*. Many of the recaptures reported by both authors were long-term recoveries, up to 16 years after tagging. Neither Hansen nor Holland, however, obtained estimates of the shedding rate.

Only two Rototags were shed; one of these was attached to the small second dorsal fin. The tag wounds of 17 sharks which had been at liberty from 11 to 38 weeks (average 18 weeks) were not severe, although the tissue was slightly swollen and inflamed. The Rototags were often completely covered with barnacles and other organisms. Apparently, the deep imprint of the numbering facilitated the attachment of invertebrates. The lettering of one Rototag recovered after 11 months was abraded and partially illegible, but that of four others recovered after 9 to 14 months was in good condition.

We consider Rototags superior to all others used in this study, particularly because they caused less damage to the fin than strap tags and because of their low shedding rate. Davies (1965) recovered 27 percent of 1,006 sharks tagged with Rototags within 8 months. In preliminary studies with captive sharks, he found that wounds healed well when the tag was attached to the first dorsal fin (personal communication). Rototags could be improved by inscribing the lettering more deeply. On attachment, the numbers and lettering should face inward.

Of 56 recaptured sharks that were tagged with strap tags, only 2 had shed their tag. One tag was lost after 1 week, probably because of faulty attachment. The sharks were at liberty from 1 to 121 weeks (average 22 weeks). We were able to examine 25 sharks that were recaptured after 8–121 weeks (average 24 weeks). The tag wounds on all were swollen and inflamed. Tags attached to the pectoral fin or very close to the fleshy base of the first dorsal fin caused especially severe wounds. Pinching and constant abrasion of tissue is inevitable with this tag, but the wounds were not as severe when the tag was attached well above the fleshy base and near the trailing edge of the first dorsal fin. Most of the tags were in good condition, and no corrosion of the Monel metal was apparent except at the point of attachment in some of the long-term recoveries. We found a thin layer of algal or bryozoan growth on some tags, but all lettering was plainly legible. One tag was deeply pitted after 11 months at sea, however. Proper clinching of the tag was difficult with large sharks unless a hole was punched prior to attachment.

We consider the strap tag usable for tagging sharks because it does not deteriorate badly and is retained over extended periods. In preliminary studies with strap tags, John Prescott (personal communication) found that tags attached to the leading edge of the first dorsal fin of captive *Triakis semifasciata* caused severe wounds.

We consider the dart tags used in this study unsuitable for tagging sharks. Dart tags were applied on 22 sharks in multiple-tag experiments. Three of these were recovered, and all had shed their dart tags after 10, 20, and 22 weeks at liberty. Further evidence of rapid shedding was provided by David Davies (personal communication) who attached dart tags to a few captive sharks and found that they were quickly shed.

FUTURE TAGGING

Results of this study have pointed out the possibilities and limitations of acquiring information on the movements and growth of sharks. To obtain information on growth, trained personnel must be on hand to measure freshly caught tagged sharks. Although impractical for most situations, the restricted movements of sharks at the Revillagigedo Islands makes such an approach feasible. Investigators could make periodic cruises to the islands and with reasonable confidence expect to capture tagged sharks. The nonmigratory juvenile sharks at the islands also present opportunities for experiments ordinarily restricted to laboratories and small ponds.

Future tagging along the Mexican coast should be complemented with catch statistics of the shark fishery. Data on species and size-frequency distributions at different seasons and years would facilitate interpretation of tagging data.

Attempts should be made to study the effects of tags and tagging on the growth rates of sharks. This work could be accomplished by other marking procedures, including internal tags, branding, or mutilation, or possibly by applying the Petersen method to length-frequency data.

Rototags, properly modified, should be used exclusively as the external tag. To obtain information on rates of shedding, they should be attached in pairs. Chapman et al (1965) described a method for estimating shedding rates by double-tagging fish with a single type of tag. Internal tags can also be used to determine shedding rates of external tags (Olsen, 1953).

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MATURATION AND SPAWNING OF TUNAS IN THE INDIAN OCEAN

by

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ABSTRACT

Tunas collected by longline fishing on the research vessel Anton Bruun during the International Indian Ocean Expedition have provided data which allow us to sketch the main features of the maturation of albacore (*Thunnus alalunga*) and of yellowfin tuna (*T. albacares*) and bigeye tuna (*T. obesus*) in the Indian Ocean. Albacore appeared to mature sexually at 90-96 cm, most yellowfin tuna at about 98 cm (although some matured at a smaller size), and bigeye tuna at 90-100 cm. Spawning areas and peak spawning seasons of albacore and yellowfin tuna were inferred from the distribution of intermediate and well-developed ovaries in the samples, but data on bigeye tuna were too sparse to delineate probable areas of spawning or determine the peak season.

INTRODUCTION

This report is based on studies of tuna ovaries collected on two cruises made by the U.S. National Science Foundation's research vessel Anton Bruun as part of the U.S. Program in Biology of the International Indian Ocean Expedition. On Anton Bruun cruise 2, longline fishing to collect biological data on tunas and other pelagic fishes was conducted on two transequatorial transects along long. 70° E and 80° E from May to July 1963, the months of the southwest monsoon. On cruise 5, similar work was conducted along long. 55° E and 75° E from February to April 1964, the months of the northeast monsoon. Each transect extended from the coast of India to at least lat. 30° S. (For exact location of longline stations, see Shomura, 1966. Ovaries examined included those from 16 albacore, 30 yellowfin tuna and 5 bigeye tuna collected in 1963, and 29 albacore, 37 yellowfin tuna, and 29 bigeye tuna caught in 1964. These samples, preserved in 10 percent formalin, were shipped to the Bureau of Commercial Fisheries Biological Laboratory in Honolulu for detailed study.

Proc. Indo-Pacific Fish. Coun., 12(II): 65-78.

TABLE I

NUMBER OF ALBACORE, YELLOWFIN AND BIGEYE TUNAS WITH OVA IN DIFFERENT DEVELOPMENTAL STAGES, BY LENGTH CLASSES

Species, and fork length (cm)	Developmental stages of ova			
	Undeveloped	Intermediate	Well developed	Total
Albacore				
70-79	1	-	-	1
80-89	6	-	-	6
90-99	15	3	2	20
100-109	10	5	3	18
Total	32	8	5	45
Yellowfin tuna				
50-59	1	-	-	1
60-69	1	-	-	1
70-79	1	-	-	1
80-89	1	-	-	1
90-99	4	2	-	6
100-109	7	1	1	9
110-119	2	2	3	7
120-129	7	8	7	22
130-139	6	4	4	14
140-149	2	2	-	4
Total	32	19	15	66[1/]
Bigeye tuna				
70-79	1	-	-	1
80-89	1	-	-	1
90-99	3	1	-	4
100-109	1	1	1	3
110-119	4	-	1	5
120-129	3	3	-	6
130-139	2	-	1	3
140-149	6	2	-	8
150-159	1	-	1	2
160-169	1	-	-	1
Total	23	7	4	34

[1/] Two yellowfin tuna that were not measured are omitted here, but included in Table III.

STAGES OF OVARIAN DEVELOPMENT

The diameters of 200 randomly selected ova from 34 albacore, 50 yellowfin tuna, and 31 bigeye tuna were measured. Although none carried fully ripe, transparent ova, some ovaries had reached an advanced stage in which large, yolked ova were easily recognizable. Diameter were measured by the use of a dissecting microscope and an ocular micrometer. A frequency distribution, based on ova diameter, was constructed from running averages of threes. Although more than one modal group was often discernible in a single ovary, the stage of maturation assigned to each ovary was based on the modal size of the most mature group. Three stages were recognized: undeveloped (mode at less than 0.20 mm), intermediate (mode between 0.20 and 0.49 mm), and well developed (mode at 0.50 mm or more).

The number of specimens in the different developmental stages by length classes is given in Table I.

All the tunas examined, regardless of length, contained some small ova. Even fish that were sexually mature, as evidenced by the presence of residual eggs, sometimes had only small ova.

In the following sections we discuss for each of the three species 1) size at maturity, 2) area of spawning, and 3) spawning season.

ALBACORE

Size of albacore at maturity was estimated by plotting the maximum modal diameter of ova against fork length for fish 76 to 103 cm long (Fig. 1). In fish shorter than 88 cm, the ovaries contained only non-yolked ova with modal diameters of about 0.10 mm. Modal diameters of about 0.50 mm were found only in fish longer than 96 cm. The absence of large, yolked ova in fish shorter than 88 cm suggests that the onset of maturity of Indian Ocean albacore begins at some length between 90 and 96 cm.

In the western North Pacific, the minimum length at sexual maturity is about 90 cm (Ueyanagi, 1957), as it also is in the Hawaiian fishery (Otsu and Uchida, 1959). Females in the South Pacific mature sexually at about 86 cm (Otsu and Hansen, 1962).

Albacore were caught on both cruises between lat. 8° S and 42° S, but maturing fish were restricted to a narrower range. During February-April 1964, albacore with intermediate and well-developed ova were caught between lat. 14° S and 28° S along long. 55° E, and between lat. 11° S and 29° S along long. 75° E; during May-July 1963 they were also caught at lat. 17° S and 19° S along long. 70° E. The shaded portion in Fig. 3 indicates the probable area of albacore spawning as deduced from the localities of capture of fish with well-developed eggs in the ovaries. Other evidence of spawning albacore in the Indian Ocean is sparse. Two albacore with ovaries in advanced stages, one of which was considered close to spawning, were taken at lat. 12° S and long. 100°-110° E in February (Ueyanagi, 1955). In the south central Indian Ocean albacore taken between lat. 22° S and 26° S in February came from a spawning group and fish taken between lat. 29° S and 33° S in March came from a group that had completed spawning (Kikawa, 1962).

Well-developed ovaries were found in specimens caught in February, March, April and June (Table II). This observation indicates the possibility of a protracted spawning season, although spawning is probably more active in February-April than in June. Such a protracted spawning season is characteristic of the albacore in the North Pacific (Otsu and Uchida, 1959; and S. Ueyanagi, personal communication) and in the South Pacific (Otsu and Hansen, 1962). Peak spawning in both the North and South Pacific Oceans also occurs in the summer (Ishii and Inoue, 1956; Ueyanagi, 1957; Otsu and Uchida, 1959; Otsu and Hansen, 1962).

TABLE II

NUMBER OF ALBACORE COLLECTED AT DIFFERENT STAGES OF MATURATION IN THE INDIAN OCEAN, BY MONTH

Month of capture	Undeveloped	Intermediate	Well developed	Total
February	2	1	1	4
March	3	1	1	5
April	14	4	2	20
May	-	-	-	-
June	10	2	1	13
July	3	-	-	3
Total	32	8	5	45

YELLOWFIN TUNA

Yellowfin tuna sampled during the Anton Bruun cruises ranged from 58 to 143 cm long; on the basis of increasing ova size of fish longer than 98 cm (Fig. 2), all fish longer than this size were considered sexually mature.

In the Pacific Ocean yellowfin tuna mature sexually between 50 and 70 cm, although the greater part of the population may reach first spawning only at about 120 cm (Schaefer and Marr, 1948; Wade, 1950; June, 1953; Bunag, 1956; Schaefer and Orange, 1956; Yuen and June, 1957; Orange, 1961). In South African waters, fish 54.0-57.5 cm long taken off the Cape in summer had immature, threadlike gonads, but fish 95.0-115.0 cm long were mature (Talbot and Penrith, 1960). Fish of intermediate size were not taken. Talbot and Penrith (1960) reported that F.P. Ommaney caught six immature yellowfin tuna off Mauritius in the western Indian Ocean; the smallest was 84 cm long.

The yellowfin tuna on which this study is based on were caught from north of the Equator to lat.30° S along long. 70° E during May-July 1963 and to as far south as lat. 36° S along long. 55° E during February-April 1964. Fish with intermediate and well-developed ovaries, however, were caught only between the Equator and lat. 20° S along long. 55° E and between lat. 4° N and 12° S along long. 75° E during February-April 1964, and at lat. 2° N and 1° S along long. 70° E and between lat. 2° N and 9° S along long. 80° E during May-July 1963. The probable spawning area of yellowfin tuna (Fig. 4) extends northward from lat. 10° to 20° S, and overlaps the northern portion of the albacore spawning area. Samples were too few to permit an estimate of the northern limit of the spawning area.

Information on yellowfin tuna in the extreme western Indian Ocean is even more limited. Ripe fish have not been caught off South Africa at any time of the year, but spawning or spent fish are occasionally taken off Kenya and Zanzibar in July (Talbot and Penrith, 1960). J. de B. Baissac (as reported by Talbot and Penrith, 1960) found many yellowfin tuna about 15 cm long on Nazareth Bank (lat. 13° - 14° S) in October. He suggested that the species reproduce in the area at about lat. 5° - 10° S.

The occurrence of well-developed ovaries in different months from February to July suggests protracted spawning. The mongh of peak spawning appeared to be February (Table III). Because of the scarcity of samples, however, this definition of the peak is considered only tentative.

TABLE III

NUMBER OF YELLOWFIN TUNA COLLECTED AT DIFFERENT STAGES OF MATURATION IN THE INDIAN OCEAN, BY MONTH

Month of capture	Undeveloped	Intermediate	Well developed	Total
February	3	5	10	18
March	3	1	-	4
April	10	4	1	15
May	12	5	-	17
June	4	1	2	7
July	1	4	2	7
Total	33	20	15	68[1]

[1] The total includes two unmeasured fish that were ommitted from Table I.

The spawning season of yellowfin tuna in the Pacific Ocean has been discussed by a number of workers for different regions: eastern Pacific--Schaefer and Marr (1948), Schaefer and Orange (1956), Orange (1961), and Klawe (1963); central and western Pacific--Marr (1948), Wade (1950), Shimada (1951), June (1953), Bunag (1956), Yuen and June (1957), Matsumoto (1958), and Kikawa (1966), and South Pacific--Legand (1960). All of the studies report year-round spawning in the tropical Pacific. Yellowfin tuna may also spawn throughout the year in the tropical Indian Ocean, although intensity probably varies greatly with the seasons.

BIGEYE TUNA

Bigeye tuna available for this study ranged from 74 to 161 cm long. The ova begin to develop in fish 90 cm long (Fig. 5). Kikawa (1953) found that the minimum size at sexual maturity for female bigeye tuna of the equatorial Pacific is about 90 to 100 cm (16-21 kg). On the basis of collections from the Hawaiian fishery, Yuen (1955) reported that the species first spawns at about 14-20 kg (86-96 cm). Our estimates of size at first spawning of the bigeye tuna in the Indian Ocean thus agree with those for the species in the Pacific Ocean.

Throughout both the 1963 and 1964 cruises, bigeye tuna with intermediate and well-developed ovaries were taken from lat. 10° N to 17° S. In 1964 well-developed ovaries were recorded only at the Equator or long. 55° E and at lat. 4° S and 12° S along long. 75° E, and intermediate ovaries only in fish caught at lat. 8° N and 17° S along long. 70° E. Only three bigeye tuna were collected from lat. 12° S to 37° S, but immature fish appeared in fairly large numbers south of lat. 40° S.

No bigeye tuna with well-developed eggs were taken in 1963. The extent of the spawning area of bigeye tuna seems to be similar to that of yellowfin tuna, although the differences in detail are not known (Fig. 6). Kume (1962) obtained ripe eggs from a bigeye tuna caught at lat. 4°-5° N, long. 62°-64° E in February (within the probable spawning area that we have defined).

Samples of bigeye tuna were too few to permit a conclusive statement on the time of spawning. Only four fish with well-developed ovaries were obtained in February and April 1964, and none in 1963 (Table IV). Year-round spawning in the central Indian Ocean was suggested by Kikawa (1966). Spawning in the equatorial Pacific extends over a long period and is subject to large monthly fluctuations (Yuen, 1955; Kikawa, 1953, 1966).

TABLE IV

NUMBER OF BIGEYE TUNA COLLECTED AT DIFFERENT STAGES OF MATURATION IN THE INDIAN OCEAN, BY MONTH

Month of capture	Undeveloped	Intermediate	Well developed	Total
February	4	1	1	6
March	1	-	-	1
April	15	4	3	22
May	-	1	-	1
June	3	1	-	4
July	-	-	-	-
Total	23	7	4	34

ACKNOWLEDGEMENTS

The U.S. National Science Foundation sponsored the field work undertaken by the Anton Bruun. The success of the U.S. Program in Biology was principally due to the guidance of Dr. John Ryther, Director of the Program. We thank Susan Kotomori and Paul Shiota, who measured the ova.

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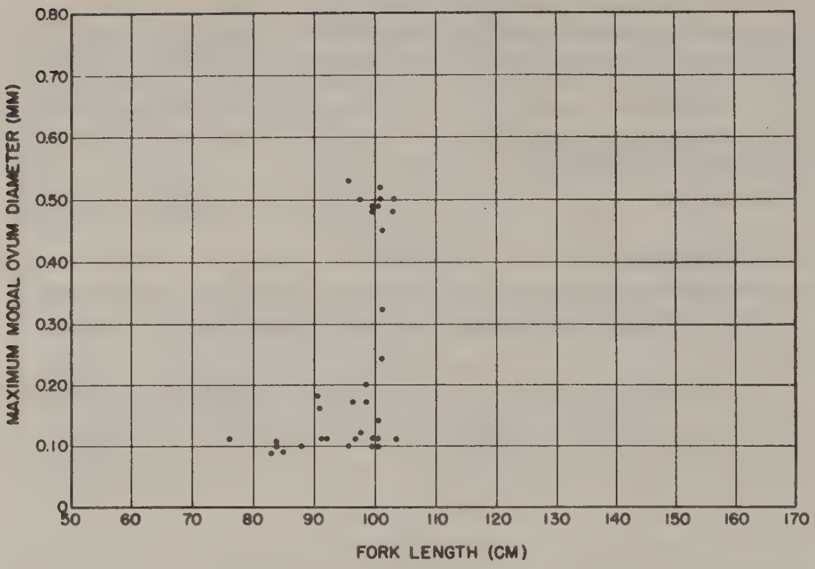


Fig. 1. Relation Between Fork Length and Maximum Modal Ovum Diameters for Albacore in the Indian Ocean.

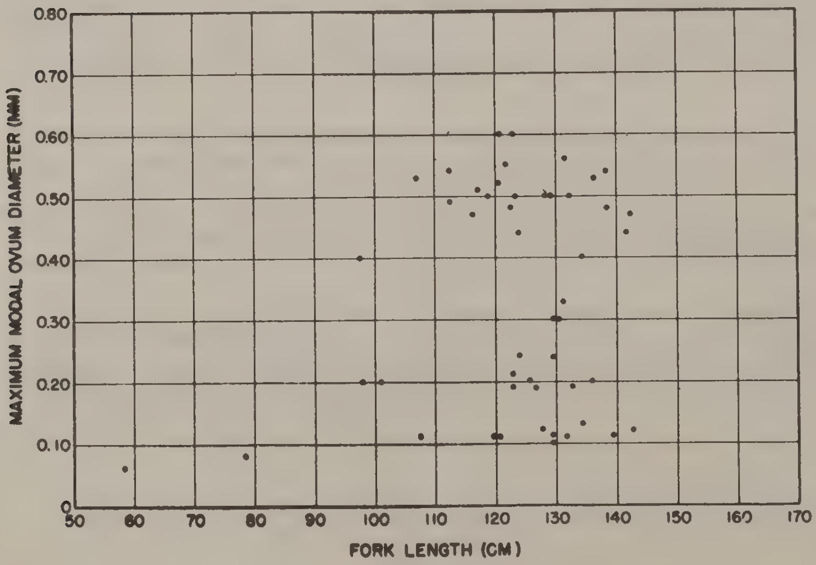
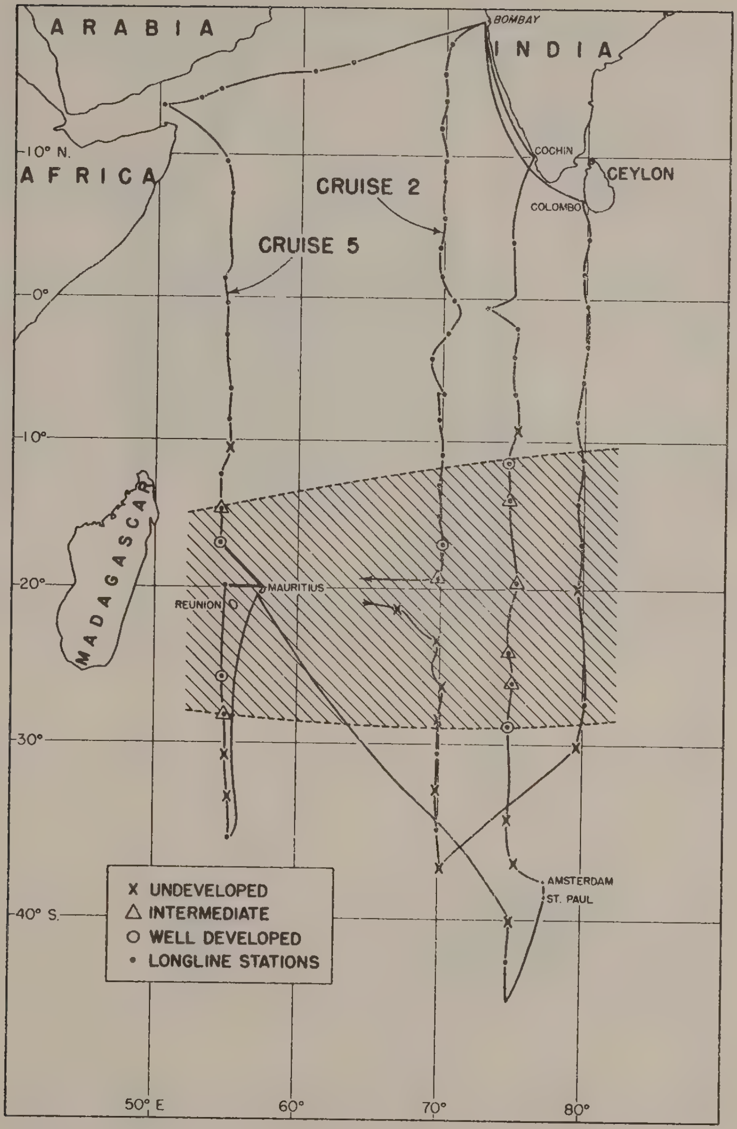


Fig. 2. Relation Between Fork Length and Maximum Modal Ovum Diameters of Yellowfin Tuna in the Indian Ocean.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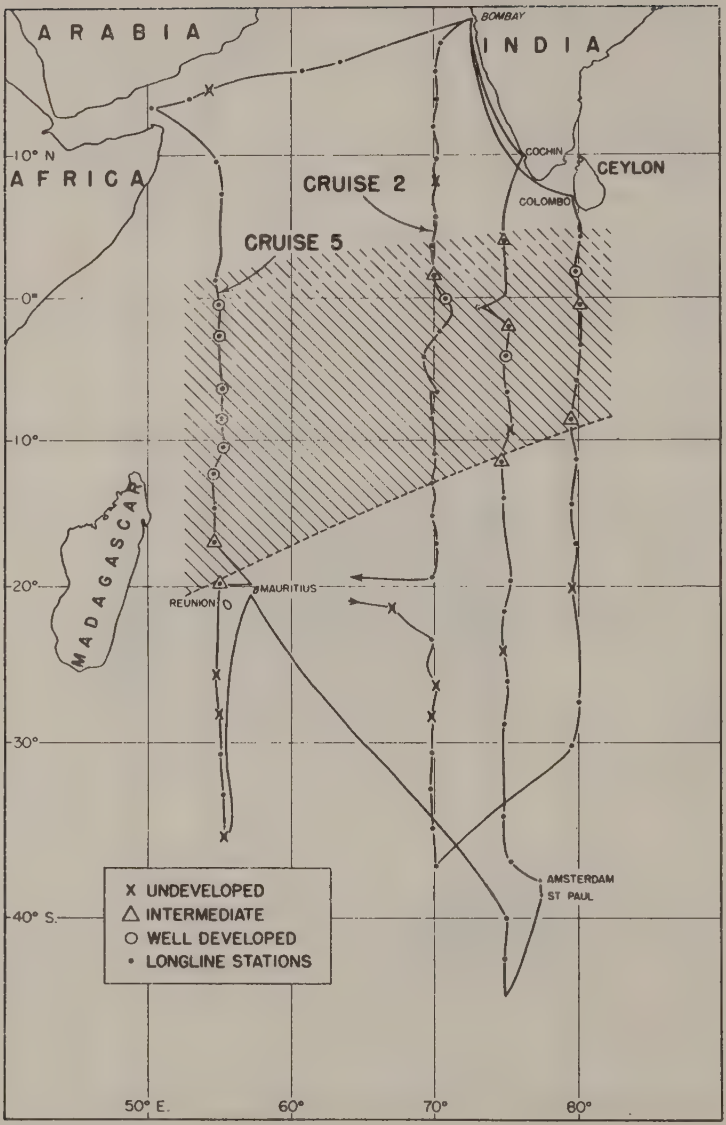
X UNDEVELOPED
△ INTERMEDIATE
○ WELL DEVELOPED
• LONGLINE STATIONS

Fig. 3. General Spawning Area and Distribution of Albacore in the Indian Ocean as Estimated from Collections of Fish with Intermediate and Well-developed Ovaries.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• LONGLINE STATIONS

Fig. 4. General Spawning Area and Distribution of Yellowfin Tuna in the Indian Ocean as Estimated from Collections of Fish with Intermediate and Well-developed Ovaries.

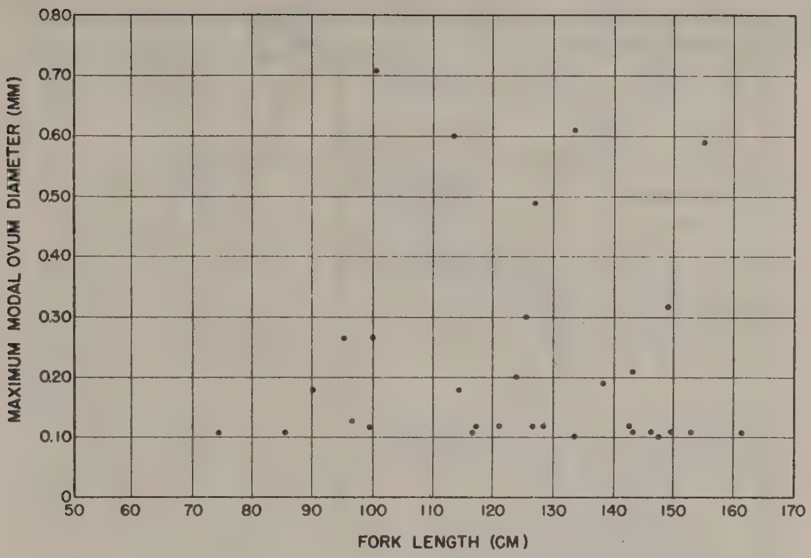
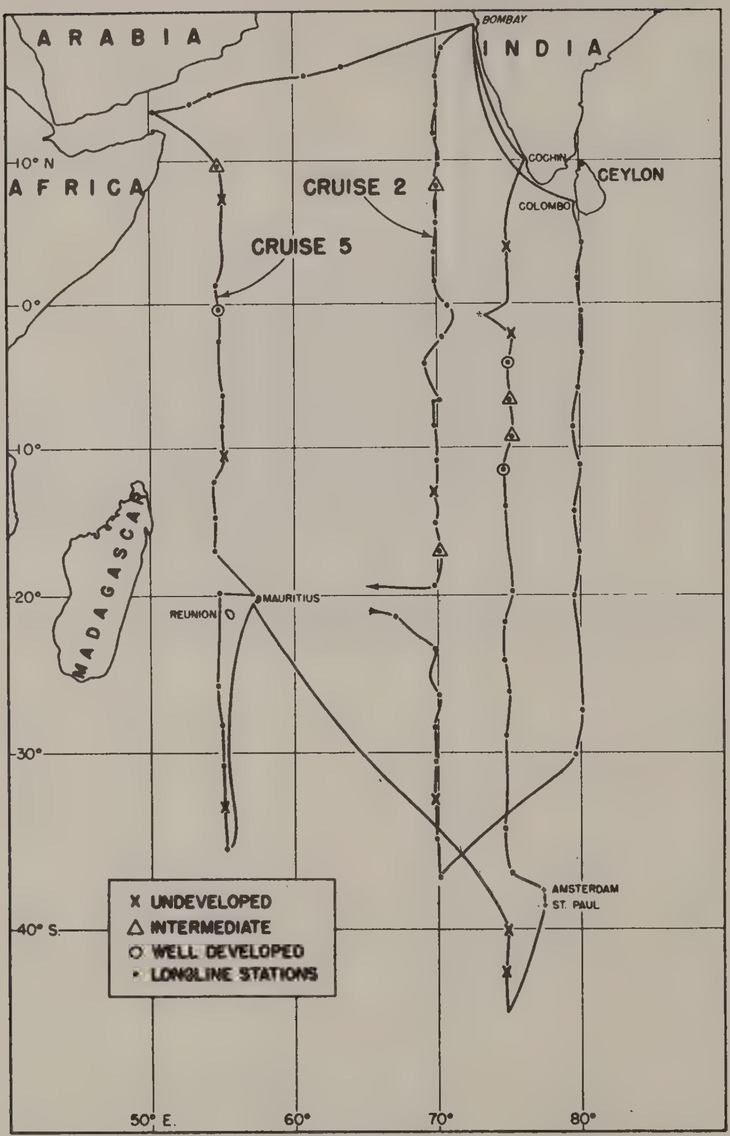


Fig. 5. Relation Between Fork Length and Maximum Modal Ovum Diameters of Bigeye Tuna in the Indian Ocean.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X UNDEVELOPED
△ INTERMEDIATE
⊙ WELL DEVELOPED
• LONGLINE STATIONS
50° E.
60°
70°
80°

Fig. 6. Localities of Capture and Stages of Maturation of Bigeye Tuna Collected by Longline in the Indian Ocean.

REPRINT FROM
Calif. Fish and Game, 53 (2) : 105–124, 1967.

AGE, LENGTH COMPOSITION, AND CATCH LOCALITIES OF SARDINE LANDINGS ON THE PACIFIC COAST OF THE UNITED STATES AND MEXICO IN 1962–63[1]

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The California catch of Pacific sardines, *Sardinops caeruleus* (Girard), during the 1962–63 season was the smallest recorded since 1916–17. In central California, 1,199 tons were taken August 1, 1962, through March 1, 1963; and in southern California, 1,477 tons were caught September 1 through March 1, 1963, for a season total of 2,676 tons. This, plus the 1962 interseason catch of 1,427 tons, brought the 1962–63 period total to 4,103 tons.

Baja California sardine landings in recent years have exceeded those of California. During the 1962–63 season (equivalent to the September 1 – March 1 season of southern California), 8,130 tons were landed. The 10,044 tons taken during the interseason brought the period total to 18,174 tons.

Central California landings were dominated by age-4 and age-5 fish (1958 and 1957 year classes), which contributed about 83% of the catch. Southern California landings were dominated by age-3 and age-4 fish (1959 and 1958 year classes), which also accounted for about 83% of the catch. In both northern and central Baja California, age-3 fish contributed over 50% of the landings. Age-2 and age-4 fish (1960 and 1958 year classes) also contributed significantly, accounting for about 40% of the numbers landed.

INTRODUCTION

This is the 17th report in a series giving the age and length composition of the catch of Pacific sardines off the Pacific Coast of North America. The data are compiled jointly by the U.S. Bureau of Commercial Fisheries and Marine Resources Operations, California Department of Fish and Game. The reports have been published on a seasonal basis since 1941–42.

We acknowledge the assistance given by Robert S. Wolf, U.S. Bureau of Commercial Fisheries, and by Anita E. Daugherty and Harold Hyatt, California Department of Fish and Game. William W. Hatton, California Academy of Sciences, gathered fish samples and landing statistics from the Baja California fishery. We also thank the cannery personnel and fishing boat captains who cooperated with our waterfront representatives.

THE FISHERY

Previous publications on the age and length composition of the Pacific sardine catch focused attention on the California fishery, which accounted for the major landings. Supplementary information on the sardine fisheries of the Pacific Northwest (1941–42 through 1948–49) and Baja California (1951–52 to date) were included. Now the Pacific Northwest fishery is nonexistent; California sardine landings have declined drastically; and, in recent years, the Baja California fishery has been the major contributor to sardine landings on the Pacific Coast. Since 1958, the area of greatest sardine catch has shifted gradually from northern Baja California (Ensenada) to central Baja California (Cedros Island), and more recently to southern Baja California (Puerto Adolfo Lopez Mateos).

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[1] Submitted for publication September 1966.

During the 1962–63 cannery season (August 1 through March 1), 1,199 tons of sardines were landed in central California.[2] In southern California, 1,477 tons were landed during the cannery season (September 1 through March 1). Thus, the statewide 1962–63 season sardine catch of 2,676 tons was the smallest recorded since 1916–17. During the interseason, March 2, 1962, to the beginning of the central and southern California seasons, total landings were 1,427 tons. This amount brought the statewide total to 4,103 tons for the 1962–63 period.

Landings during the cannery season include deliveries to both the cannery and fresh-fish markets. Most of the fish in the latter are frozen and sold for bait, chiefly in the San Francisco region, where sport fishermen highly regard sardines as bait.

Interseason sardine landings include fish sold not only for bait, but also for canning as a special pack. This pack, first permitted in 1929, gives canners an opportunity to pack sardines in small cans to compete with imported sardines. The privilege was suspended by the California Legislature in 1949 because of the decline in sardine landings, but was reinstated June 1, 1961. Only one southern California processor took advantage of this during the 1962 interseason.

TABLE 1
Calendar Dates of Lunar Months During the 1962–63 Period

Lunar month	Lunar period*	Dates
"March"	524	February 20 (1962)–March 20
"April"	525	March 21–April 18
"May"	526	April 19–May 18
"June"	527	May 19–June 16
"July"	528	June 17–July 16
"August A"†	529	July 17–August 14
"August B"	530	August 15–September 13
"September"	531	September 14–October 12
"October"	532	October 13–November 11
"November"	533	November 12–December 11
"December"	534	December 12–January 10 (1963)
'January"	535	January 11–February 8
February"	536	February 9–March 10

* Lunar months have been numbered serially since "November" 1919.
† Because lunar months are shorter than calendar months it is necessary to add an additional lunar month every three years to compensate.

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[2] Landings were allowed on March 2 in central and southern California.

In Baja California, sardine fishing is permitted throughout the year. For purposes of comparison, the fishing period is divided into season and interseason, so the dates will correspond with those of southern California. Season and interseason landings amounted to 8,130 and 10,044 tons, respectively, for a 1962–63 period total of 18,174 tons.

CENTRAL CALIFORNIA

In central California (Point Arguello northward), the season opened August 1, 1962, and ended March 1, 1963. Fishing started promptly in central California, with a tentative price of $50 per ton for sardines, the price paid during the preceding season. The price for jack mackerel, *Trachurus symmetricus,* and Pacific mackerel, *Scomber diego,* was also continued at the level of the preceding season, $42.50 per ton. On October 8, to conform to southern California quotations, the price was set at $60 per ton for sardines, $42.50 for mackerel, and $47.50 for mixed sardines and mackerel. During the last 14 days of the "August A" lunar period (Table 1), 384 tons were landed.

The catch of 424 tons during "August B" was the highest of the season. The "September" catch of 297 tons was followed by 53 tons during "October". Fishing during successive lunar periods yielded smaller catches, to a low of 6 tons during "January". The total for the region was 1,199 tons.

Nearly 95% of the central California catch was taken south of Monterey Bay, between Point Sur and Morro Bay. Most of the tonnage was taken off Point Lopez, about halfway between Point Sur and Piedras Blancas. The remainder came from Monterey Bay (Figure 1, Table 2).

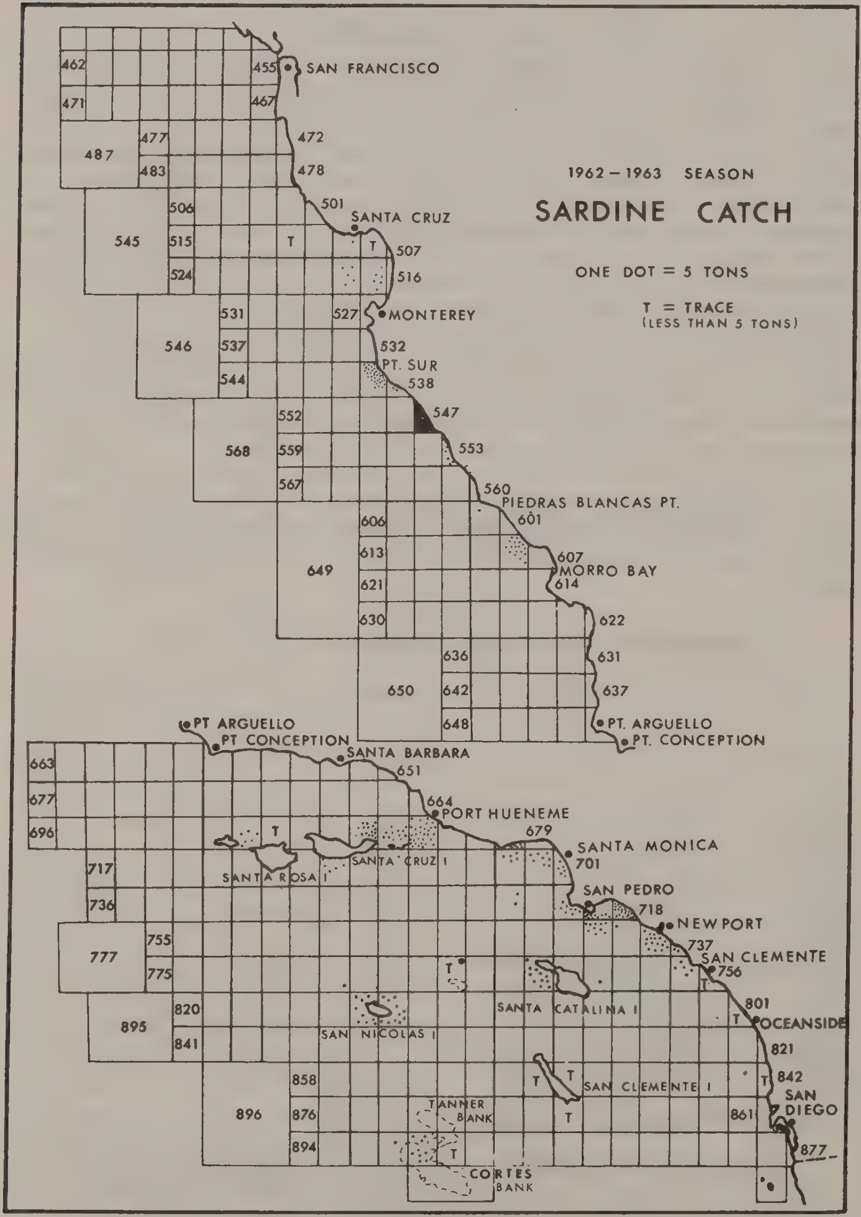
TABLE 2

Sardine Catch by General Fishing Areas for 1962–63 Period

General areas	Block numbers	Interseason*		Season†		Total	
		Pounds	Percentage	Pounds	Percentage	Pounds	Percentage
Point Arena	401-421	0	0.0	0	0.0	0	0.0
Bodega Head	422-445	0	0.0	94	T	94	T
San Francisco	446-471	0	0.0	0	0.0	0	0.0
Pigeon Point	472-506	0	0.0	0	0.0	0	0.0
Monterey	507-531	3,966	0.1	114,003	2.1	117,969	1.4
Point Sur	532-552	0	0.0	1,387,067	25.9	1,387,067	16.9
Piedras Blancas	553-606	0	0.0	80,150	1.5	80,150	1.0
Point Buchon	607-630	0	0.0	184,500	3.5	184,500	2.2
Point Sal	631-648	0	0.0	0	0.0	0	0.0
Santa Barbara	651-657, 665-671	0	0.0	0	0.0	0	0.0
Port Hueneme	664, 680-683, 703-706, 722-725	0	0.0	437,857	8.2	437,857	5.3
Santa Cruz Island	684-690, 707-713, 726-732	0	0.0	404,517	7.6	404,517	4.9
Point Vicente	679, 701, 702, 718-721, 737-742	669,383	23.4	820,165	15.3	1,489,548	18.2
Oceanside	756-758, 801-804, 821-825	0	0.0	54,230	1.0	54,230	0.7
Santa Catalina Island	759-762, 805-808	192,700	6.8	120,787	2.3	313,487	3.8
Santa Barbara Island	743-745, 763-765, 809-811	0	0.0	964	T	964	T
San Nicolas Island	746-749, 766-769, 812-815, 833-836	0	0.0	194,506	3.6	194,506	2.4
San Diego	842-846, 860-864, 877-882	0	0.0	17,775	0.3	17,775	0.2
San Clemente Island	826-832, 847-853, 865-869	4,100	0.2	1,235	T	5,335	0.1
Tanner and Cortes Banks	854-855, 870-873, 888-891, 897	0	0.0	106,882	2.0	106,882	1.3
Totals by area		**870,149**	**30.5**	**3,924,732**	**73.3**	**4,794,881**	**58.4**
Pounds of unknown origin not included in above		1,984,680	69.5	1,426,442	26.7	3,411,122	41.6
Total catch		**2,854,829**	**100.0**	**5,351,174**	**100.0**	**8,206,003**	**100.0**

*Interseason: north of Pt. Arguello Mar. 2–July 31; south of Pt. Arguello Mar. 2–Aug. 31.
†Season: north of Pt. Arguello Aug. 1–Mar. 1; south of Pt. Arguello Sept. 1–Mar. 1.

Only 3 canneries operated in central California: 1 at San Francisco, 1 at Moss Landing, and 1 at Monterey. Nine lampara boats fished exclusively in central California; 6 purse seiners, 4 large (60 feet or over) and 2 small, also fished off southern California.


1962 – 1963 SEASON
SARDINE CATCH
ONE DOT = 5 TONS
T = TRACE
(LESS THAN 5 TONS)
SAN FRANCISCO
SANTA CRUZ
MONTEREY
PT. SUR
PIEDRAS BLANCAS PT.
MORRO BAY
PT. ARGUELLO
PT. CONCEPTION
PT ARGUELLO
PT CONCEPTION
SANTA BARBARA
PORT HUENEME
SANTA MONICA
SAN PEDRO
NEWPORT
SAN CLEMENTE
OCEANSIDE
SAN DIEGO
SANTA ROSA I
SANTA CRUZ I
SANTA CATALINA I
SAN NICOLAS I
SAN CLEMENTE I
TANNER BANK
CORTES BANK
T
455
462
467
471
472
477
478
483
487
501
506
507
515
516
524
527
531
532
537
538
544
545
546
547
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553
559
560
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568
601
606
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621
622
630
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642
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651
663
664
677
679
696
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717
718
736
737
755
756
775
777
801
820
821
841
842
858
861
876
877
894
895
896

FIGURE 1—California sardine catch origins, 1962–63 season. Dots are placed in approximate locations, relative to land masses, where fish are known to have been taken.

SOUTHERN CALIFORNIA

The season opened September 1 in southern California. With the exception of a few boats, the fleet did not fish until the evening of October 8, when a price dispute was resolved. At that time the price was set at $60 per ton for sardines, $42.50 for mackerel, and $47.50 for mixed sardines and mackerel.

During ''August B'', 16 tons were landed, followed by 240 tons in ''September''. This was followed by a catch of 485 tons in ''October''. Subsequent landings during the ''November'' through ''February'' lunar periods ranged from 127 to 229 tons. The total for the region during the regular season was 1,477 tons.

Southern California sardines were taken along the coast from Port Hueneme to La Jolla, and from offshore islands and banks. The primary catch areas were near Port Hueneme; Santa Monica Bay; San Pedro; Newport; Santa Cruz and San Nicolas islands; and Cortes and Tanner banks (Figure 1, Table 2). Sardines were generally mixed with mackerel; only a few sets were made on ''pure'' schools of sardines.

As in 1961–62, 7 canneries operated in southern California: 1 at Oxnard and 6 in the Los Angeles-Long Beach Harbor area.

A total of 75 boats, comprising 41 large purse seiners and 34 small purse seiners and lampara boats, fished exclusively in southern California. In addition, 4 large and 2 small purse seiners also fished in central California.

BAJA CALIFORNIA

Seven canneries processed sardines in Baja California during the season: 5 at Ensenada, 1 at Isla Cedros, and 1 in southern Baja California at Puerto Adolfo Lopez Mateos. The southernmost cannery lies about 4 miles within Boca de la Soledad, about 35 miles northeast of Cabo San Lazaro (Figure 2).

The sardine fishery operates throughout the year off Baja California. Landings in the areas of northern Baja California (Ensenada), central Baja California (Isla Cedros), and southern Baja California (Puerto Adolfo Lopez Mateos) amounted to 8,130 tons during the season. The tonnage landed during the comparable period in 1961–62 was 8,551 tons. The 1962 interseason landings were 10,044 tons.

Weather conditions were generally favorable throughout the 1962–63 period; however, domestic demand for canned sardines was low, and fishing effort declined.

Ensenada canneries received about 75% of their sardines through transshipments by refrigerated vessel from central Baja California waters off Santo Domingo in Bahia Sebastian Vizcaino. The remaining portion came from the northern area between the United States-Mexico border and Punta Soledad. The cannery at Isla Cedros was supplied with fish caught in the waters of Bahia Sebastian Vizcaino. The cannery at Puerto Adolfo Lopez Mateos was supplied by purse seiners which ranged from Punta San Juanico south to Punto San Tosca. The majority of the catches came from Bahia Magdalena.

The Baja California fishing fleet consisted of 30 vessels that spent most of their time fishing for sardines and mackerel. The fleet was composed of large (60 feet and over) and small purse seiners, most of

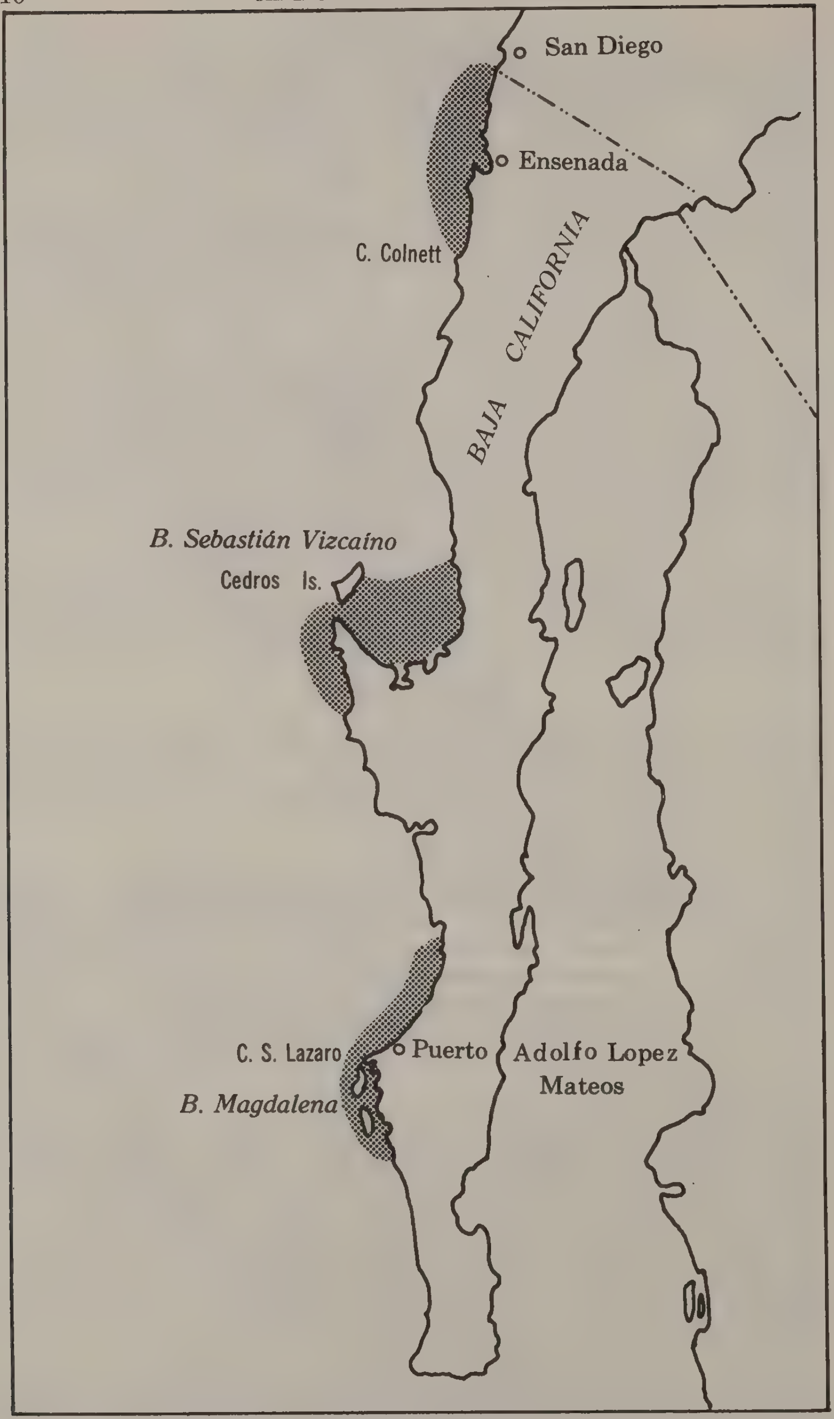
San Diego
Ensenada
C. Colnett
BAJA CALIFORNIA
B. Sebastián Vizcaíno
Cedros Is.
C. S. Lazaro
Puerto Adolfo Lopez Mateos
B. Magdalena

FIGURE 2—Baja California sardine catch areas, 1962–63 season. The shaded areas indicate locations where sardines were concentrated, as determined by fish sampling data and from information obtained from spokesmen of the sardine canneries.

them locally owned. Twenty-three were based at Ensenada, 4 at Isla Cedros, and 3 at Puerto Adolfo Lopez Mateos. Four of the Ensenada based vessels landed sardines at Isla Cedros during part of the year. Six of the larger Ensenada vessels are equipped with refrigerated holds, enabling them to fish in the Isla Cedros area and return their sardine catches to Ensenada. These vessels also are equipped with powerblocks for hauling in the purse seines. Occasionally the Baja California fleet was augmented by vessels from San Pedro, California.

The amount paid to the fishermen for sardines in Baja California varied with the operational status of their boats. Cannery-owned vessels received $32.60 per ton for sardines. Privately-owned vessels, usually owned and operated by Americans, received up to $42 per ton. One company, landing fish for another, received about $48 per ton. The price for mixed sardine and mackerel landings was about $32 per ton. The prices quoted are the maximums; however, the ranges were so slight that they are close to the averages for the period.

AGE AND LENGTH COMPOSITION

Each sardine length sample usually consists of 50 fish, measured to the nearest millimeter SL. Ten fish are taken randomly from each sample for age determinations. To estimate the year-class composition of a region's catch during a lunar month, three things are required: (i) an estimate of the number of fish landed (obtained by dividing total weight landed by the mean weight of the fish sampled); (ii) a summary of the age composition stratified by centimeters of length, and giving the numbers of fish by year class within each length stratum; and (iii) a length-frequency distribution of the total number of fish sampled, also stratified by cm intervals. The total number of fish measured in each length stratum of the frequency distribution is allocated to year classes in the same proportions as those aged in each length stratum. These data are then summed by year classes. The age or year-class composition of the catch is then obtained by allocating the estimated number of fish landed to year classes in the same proportions as in the year-class summation. Other details of the method are given by Felin and Phillips (1948).

Length samples for 1962–63 included 633 fish from central California landings, 1,100 from southern California, 700 from northern Baja California, and 900 from central Baja California. Although substantial landings of sardines are made in southern Baja California, they are not yet being sampled.

Two size groups were evident in samples from central and southern California (Figure 3), but the separation was less distinct in southern California. Single size groups occurred in northern and central Baja California.

Central California landings consisted primarily of large sardines landed during the "August A" through "October" periods. The lengths ranged from 224 to 266 mm, and averaged 245 mm; the average weight was 0.411 pounds. The 123 fish taken for age determinations consisted of 5 year classes: 1956, 1957, 1958, 1960, and 1961 (Table 3). Catches were dominated by 4- and 5-year-olds (1958 and 1957 year classes) which contributed 83% of the estimated numbers landed (Table 12).

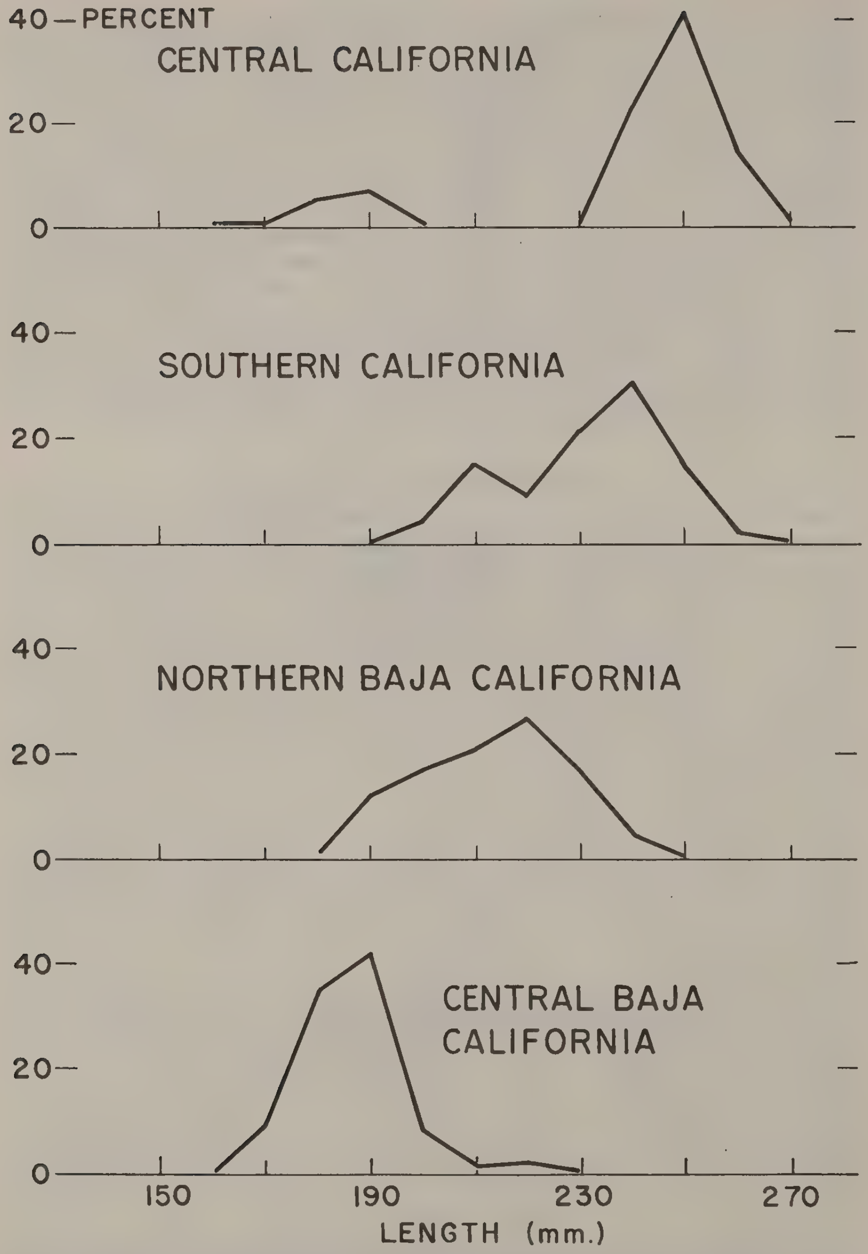

FIGURE 3—Percentage length composition of sardines sampled during the 1962–63 commercial season, by region of capture. Data are plotted at 10-mm intervals.

TABLE 3

Length Composition of Year Classes in Sardine Samples from the Central California Commercial Catch, 1962–63 Season

Standard length (mm)	Year class							Totals	
	1962	1961	1960	1959	1958	1957	1956	Aged	Measured
130	--	--	--	--	--	--	--	--	1
154	--	--	--	--	--	--	--	--	2
156	--	--	--	--	--	--	--	--	--
158	--	--	--	--	--	--	--	--	1
160	--	--	--	--	--	--	--	--	--
162	--	--	--	--	--	--	--	--	--
164	--	--	1	--	--	--	--	1	1
166	--	--	--	--	--	--	--	--	1
168	--	--	--	--	--	--	--	--	--
170	--	--	--	--	--	--	--	--	1
172	--	1	--	--	--	--	--	1	2
174	--	1	1	--	--	--	--	2	6
176	--	--	3	--	--	--	--	3	7
178	--	2	2	--	--	--	--	4	10
180	--	--	1	--	--	--	--	1	12
182	--	--	1	--	--	--	--	1	14
184	--	--	1	--	--	--	--	1	11
186	--	--	1	--	--	--	--	1	12
188	--	--	2	--	--	--	--	2	5
190	--	1	--	--	--	--	--	1	5
192	--	--	--	--	--	--	--	--	2
194	--	--	1	--	--	--	--	1	1
196	--	--	1	--	--	--	--	1	2
198	--	--	1	--	--	--	--	1	1
200	--	--	--	--	--	--	--	--	1
202	--	--	--	--	--	--	--	--	--
204	--	--	--	--	--	--	--	--	--
206	--	--	--	--	--	--	--	--	--
208	--	--	--	--	--	--	--	--	--
210	--	--	--	--	--	--	--	--	--
212	--	--	--	--	--	--	--	--	--
214	--	--	--	--	--	--	--	--	--
216	--	--	--	--	--	--	--	--	--
218	--	--	--	--	--	--	--	--	--
220	--	--	--	--	--	--	--	--	--
222	--	--	--	--	--	--	--	--	--
224	--	--	--	--	1	1	--	2	3
226	--	--	--	--	--	--	--	--	--
228	--	--	--	--	--	--	--	--	1
230	--	--	--	--	--	--	--	--	6
232	--	--	--	--	1	1	--	2	15
234	--	--	--	--	--	2	--	2	20
236	--	--	--	--	5	--	1	6	32
238	--	--	--	--	2	2	3	7	36
240	--	--	--	--	3	3	--	6	46

TABLE 3—Continued

Length Composition of Year Classes in Sardine Samples from the Central California Commercial Catch, 1962–63 Season

Standard length (mm)	Year class							Totals	
	1962	1961	1960	1959	1958	1957	1956	Aged	Measured
242	--	--	--	--	5	4	2	11	62
244	--	--	--	--	5	7	1	13	62
246	--	--	--	--	7	5	--	12	54
248	--	--	--	--	2	4	3	9	37
250	--	--	--	--	2	6	1	9	46
252	--	--	--	--	3	2	3	8	32
254	--	--	--	--	1	1	--	2	26
256	--	--	--	--	3	1	--	4	19
258	--	--	--	--	--	5	--	5	16
260	--	--	--	--	1	1	1	3	12
262	--	--	--	--	1	--	--	1	5
264	--	--	--	--	--	--	--	--	3
266	--	--	--	--	--	--	--	--	2
Totals	--	5	16	--	42	45	15	123	633
Mean lengths	--	178	182	--	245	246	246	246	245

Sardines in southern California samples ranged from 188 to 266 mm and had a mean of 228 mm; the average weight was 0.345 pounds (Table 4). Catches were dominated by 3- and 4-year-olds (1959 and 1958 year classes), which constituted about 83% of the landings. The 5- and 6-year-olds (1957 and 1956 year classes) contributed about 15 and 1%, respectively (Table 12).

TABLE 4

Length Composition of Year Classes in Sardine Samples from the Southern California Commercial Catch, 1962–63 Season

Standard length (mm)	Year class							Totals	
	1962	1961	1960	1959	1958	1957	1956	Aged	Measured
188	--	--	--	--	--	--	--	--	1
190	--	--	--	--	--	--	--	--	2
192	--	--	--	--	--	--	--	--	3
194	--	--	--	2	--	--	--	2	6
196	--	--	--	1	--	--	--	1	5
198	--	--	--	2	--	--	--	2	12
200	--	--	--	4	--	--	--	4	20
202	--	--	--	7	2	--	--	9	42
204	--	--	--	7	--	--	--	7	27
206	--	--	--	1	--	--	--	1	32
208	--	--	--	9	2	--	--	11	37
210	--	--	--	3	--	--	--	3	33
212	--	--	--	4	--	--	--	4	17
214	--	--	--	5	1	--	--	6	22
216	--	--	--	1	2	1	--	4	17
218	--	--	--	1	2	--	--	3	20
220	--	--	--	3	3	--	--	6	28
222	--	--	--	7	--	1	--	8	35
224	--	--	--	1	4	--	--	5	43
226	--	--	--	6	5	2	--	13	43
228	--	--	--	2	2	--	--	4	55
230	--	--	--	5	6	1	--	12	62
232	--	--	--	7	8	4	--	19	65
234	--	--	--	3	8	3	1	15	70
236	--	--	--	3	9	3	1	16	64
238	--	--	--	4	3	4	--	11	68
240	--	--	--	1	3	4	--	8	68
242	--	--	--	1	3	4	1	9	59
244	--	--	--	1	7	--	--	8	34
246	--	--	--	--	8	1	--	9	34
248	--	--	--	1	2	4	--	7	21
250	--	--	--	1	4	1	--	6	24
252	--	--	--	--	2	2	--	4	15
254	--	--	--	--	--	--	--	--	5
256	--	--	--	--	--	--	--	--	3
258	--	--	--	--	--	--	--	--	2
260	--	--	--	--	--	--	--	--	1
262	--	--	--	--	--	--	--	--	2
264	--	--	--	--	--	--	--	--	2
266	--	--	--	--	--	--	--	--	1
Totals	--	--	--	93	86	35	3	217	1,100
Mean lengths	--	--	--	218	234	238	237	228	228

As in preceding seasons, fish sampled in Baja California were smaller than those taken in California. Lengths of 700 sardines sampled from northern Baja California ranged from 172 to 248 mm and had a mean of 209 mm (Table 5). The weight averaged 0.316 pounds. The 3-year-olds (1959 year class) were dominant and contributed nearly 50% of the numbers aged. The 900 sardines from central Baja California were considerably smaller; lengths ranged from 152 to 226 mm and averaged 183 mm (Table 6). Here, too, the 3-year-olds (1959 year class) were dominant and contributed slightly over 50% of the number aged. Total landings from Baja California, when converted into numbers of fish, consisted mainly of 3-year-olds (1959 year class), but 2- and 4-year-olds did contribute significantly to the catch (Table 12).

The 1962 interseason landings in California were negligible. Measurements were obtained from only 101 fish in central California; lengths ranged from 228 to 274 mm (Table 7). The fish were sampled from May through July 1962, and only 25 were used in age analysis. The 1958 year class was the dominant contributor. Southern California landings, sampled during May and June, consisted of 250 fish from 186 to 256 mm long (mean 228 mm). The 1957 and 1958 year classes were the major contributors.

Interseason samples from northern Baja California catches consisted of 950 fish that ranged from 164 to 240 mm and averaged 203 mm (Table 9). Samples from central Baja California consisted of 700 fish ranging from 142 to 222 mm with a mean of 176 mm (Table 10). The interseason catch of Baja California was composed principally of the 1958 year class, 44%; the 1957 year class contributed 28% and the 1959 year class, 18% (Table 11).

TABLE 5

Length Composition of Year Classes in Sardine Samples from the Northern Baja California Commercial Catch, 1962–63 Season

Standard length (mm)	Year class							Totals	
	1962	1961	1960	1959	1958	1957	1956	Aged	Meas-ured
172	--	--	--	--	--	--	--	--	1
174	--	--	--	--	--	--	--	--	--
176	--	--	--	--	--	--	--	--	1
178	--	--	--	--	--	--	--	--	2
180	--	--	--	--	--	--	--	--	8
182	--	--	--	--	--	--	--	--	10
184	--	--	--	1	--	--	--	1	23
186	--	--	2	--	--	--	--	2	17
188	--	--	3	--	--	--	--	3	16
190	--	--	1	2	--	1	--	4	19
192	--	--	--	2	1	--	--	3	25
194	--	--	2	1	--	--	--	3	30
196	--	--	1	2	--	--	--	3	21
198	--	--	--	3	--	--	--	3	19
200	--	--	--	3	2	--	--	5	27
202	--	--	--	1	1	--	--	2	23
204	--	--	3	2	1	1	--	7	27
206	--	--	2	2	2	1	--	7	29
208	--	--	1	7	2	--	--	10	33
210	--	--	--	4	2	--	--	6	32
212	--	--	--	5	2	--	--	7	39
214	--	--	--	4	4	2	1	11	40
216	--	--	1	4	4	1	--	10	34
218	--	--	--	6	1	--	--	7	36
220	--	--	1	5	1	--	--	7	36
222	--	--	--	2	3	--	1	6	31
224	--	--	--	3	4	1	--	8	33
226	--	--	2	2	5	--	--	9	26
228	--	--	1	3	2	--	--	6	16
230	--	--	--	--	2	--	--	2	12
232	--	--	1	--	2	--	--	3	15
234	--	--	1	2	--	--	--	3	13
236	--	--	--	--	--	--	--	--	3
238	--	--	--	--	1	--	--	1	1
240	--	--	--	--	--	--	--	--	1
242	--	--	--	--	--	--	--	--	--
244	--	--	--	--	--	--	--	--	--
246	--	--	--	--	--	--	--	--	--
248	--	--	--	--	--	1	--	1	1
Totals	--	--	22	66	42	8	2	140	700
Percentage	--	--	15.71	47.14	30.00	5.72	1.43	100.00	
Mean lengths	--	--	206	211	218	215	218	213	209

TABLE 6

Length Composition of Year Classes in Sardine Samples from the Central Baja California Commercial Catch, 1962–63 Season

Standard length (mm)	Year class							Totals	
	1962	1961	1960	1959	1958	1957	1956	Aged	Measured
152	--	--	--	--	--	--	--	--	1
154	--	--	--	--	--	--	--	--	--
156	--	--	--	--	--	--	--	--	1
158	--	--	--	--	--	--	--	--	1
160	--	--	--	--	--	--	--	--	2
162	--	--	1	1	--	--	--	2	5
164	--	--	--	--	--	--	--	--	8
166	--	--	1	--	1	--	--	2	7
168	--	--	2	3	1	--	--	6	26
170	--	--	3	3	--	1	--	7	36
172	--	--	2	2	--	--	--	4	38
174	--	--	3	11	2	--	--	16	60
176	--	--	3	3	3	--	--	9	65
178	--	--	2	7	--	--	--	9	87
180	--	--	6	9	4	--	--	19	76
182	--	--	1	6	3	2	1	13	87
184	--	--	2	11	7	1	--	21	89
186	--	--	3	6	3	3	--	15	74
188	--	--	7	6	6	3	1	23	73
190	--	--	2	8	1	--	--	11	51
192	--	--	1	3	--	--	--	4	32
194	--	--	--	2	--	1	--	3	15
196	--	--	--	1	--	1	--	2	9
198	--	--	--	1	--	--	--	1	11
200	--	--	--	--	--	--	--	--	5
202	--	--	--	2	--	--	--	2	7
204	--	--	--	--	--	--	--	--	1
206	--	--	--	2	--	1	--	3	3
208	--	--	--	--	--	--	--	--	2
210	--	--	--	--	1	--	--	1	2
212	--	--	--	1	--	--	--	1	3
214	--	--	--	--	--	--	--	--	1
216	--	--	--	--	--	1	--	1	4
218	--	--	--	--	1	--	--	1	8
220	--	--	--	1	1	--	--	2	4
222	--	--	--	--	--	--	--	--	3
224	--	--	--	1	--	--	--	1	2
226	--	--	--	--	--	--	--	--	1
Totals	--	--	39	90	34	14	2	179	900
Percentage	--	--	21.79	50.28	18.99	7.82	1.12	100.00	
Mean lengths	--	--	179	184	185	189	185	184	183

TABLE 7

Length Composition of Year Classes in Sardine Samples from the Central California Interseason Catch, 1962 (May through July)

Standard length (mm)	Year class							Totals	
	1961	1960	1959	1958	1957	1956	1955	Aged	Measured
228	--	--	--	--	--	--	--	--	1
230	--	--	--	--	--	--	--	--	--
232	--	--	--	--	--	--	--	--	--
234	--	--	--	--	--	--	--	--	1
236	--	--	--	1	--	--	--	1	3
238	--	--	--	--	1	--	--	1	5
240	--	--	--	1	--	--	--	1	3
242	--	--	--	2	--	--	--	2	7
244	--	--	--	1	--	1	--	2	3
246	--	--	--	1	--	1	--	2	8
248	--	--	--	1	1	--	--	2	9
250	--	--	--	1	3	--	--	4	12
252	--	--	--	2	--	1	--	3	8
254	--	--	--	--	--	--	--	--	8
256	--	--	--	2	1	--	--	3	11
258	--	--	--	--	1	--	--	1	11
260	--	--	--	1	--	--	--	1	6
262	--	--	--	--	--	--	--	--	1
264	--	--	--	1	--	--	--	1	2
266	--	--	--	--	--	1	--	1	1
268	--	--	--	--	--	--	--	--	--
270	--	--	--	--	--	--	--	--	--
272	--	--	--	--	--	--	--	--	--
274	--	--	--	--	--	--	--	--	1
Totals	--	--	--	14	7	4	--	25	101
Mean lengths	--	--	--	249	250	252	--	250	250

TABLE 8

Length Composition of Year Classes in Sardine Samples from the Southern California Interseason Catch, 1962 (May and June)

Standard length (mm)	Year class							Totals	
	1961	1960	1959	1958	1957	1956	1955	Aged	Measured
186	--	1	--	--	--	--	--	1	1
188	--	--	--	--	--	--	--	--	--
190	--	--	--	--	--	--	--	--	--
192	--	--	--	--	--	--	--	--	--
194	--	--	--	--	--	--	--	--	2
196	--	--	--	--	--	--	--	--	--
198	--	--	--	--	--	--	--	--	--
200	--	--	--	--	--	--	--	--	--
202	--	--	--	--	--	--	--	--	--
204	--	--	--	--	--	--	--	--	--
206	--	--	1	--	--	--	--	1	1
208	--	--	--	--	--	--	--	--	1
210	--	--	--	--	--	--	--	--	1
212	--	--	--	--	--	--	--	--	3
214	--	--	--	--	1	--	--	1	7
216	--	--	--	1	2	--	--	3	15
218	--	--	--	--	1	1	--	2	13
220	--	--	--	1	1	--	--	2	8
222	--	--	--	2	2	--	--	4	17
224	--	--	--	1	2	--	--	3	18
226	--	--	--	2	2	--	--	4	26
228	--	--	--	2	1	--	--	3	18
230	--	--	--	2	4	--	--	6	24
232	--	--	--	--	1	1	--	2	16
234	--	--	--	2	1	1	--	4	15
236	--	--	--	1	1	2	--	4	16
238	--	--	--	--	--	--	--	--	14
240	--	--	--	--	1	--	--	1	9
242	--	--	--	--	2	--	--	2	10
244	--	--	--	1	--	--	--	1	5
246	--	--	--	--	--	--	--	--	3
248	--	--	--	1	--	1	--	2	4
250	--	--	--	--	--	--	--	--	1
252	--	--	--	--	--	--	--	--	--
254	--	--	--	--	--	--	--	--	1
256	--	--	--	--	--	--	--	--	1
Totals	--	1	1	16	22	6	--	46	250
Mean lengths	--	186	206	229	227	234	--	228	228

TABLE 9

Length Composition of Year Classes in Sardine Samples from the Northern Baja California Interseason Catch, 1962

Standard length (mm)	Year class							Totals	
	1961	1960	1959	1958	1957	1956	1955	Aged	Measured
164	--	--	--	--	--	--	--	--	1
166	--	--	--	--	--	--	--	--	2
168	--	1	1	1	--	--	--	3	5
170	--	--	--	1	--	--	--	1	6
172	--	1	--	--	--	--	--	1	9
174	--	--	--	--	--	--	--	--	12
176	--	--	--	1	1	--	--	2	11
178	--	--	--	--	--	--	--	--	10
180	--	--	2	--	--	--	--	2	11
182	--	--	--	--	2	--	--	2	18
184	--	2	1	--	1	1	--	5	20
186	--	1	1	--	1	--	--	3	19
188	--	1	1	--	1	--	--	3	23
190	--	2	4	--	1	--	--	7	22
192	--	1	1	--	--	--	--	2	19
194	--	1	1	2	--	--	--	4	33
196	--	2	3	1	--	--	--	6	35
198	--	3	4	--	--	1	--	8	42
200	--	1	--	2	1	--	--	4	46
202	--	--	3	5	1	2	--	11	65
204	--	1	4	7	4	--	--	16	70
206	--	--	3	9	1	--	--	13	73
208	--	1	6	7	5	1	--	20	75
210	--	--	9	10	7	--	--	26	76
212	--	1	2	7	1	1	--	12	67
214	--	1	5	6	3	--	--	15	40
216	--	--	2	1	--	2	--	5	35
218	--	1	1	--	2	--	--	4	28
220	--	--	2	2	2	--	--	6	29
222	--	--	--	1	1	--	--	2	16
224	--	--	--	--	1	--	--	1	14
226	--	--	1	1	--	--	--	2	9
228	--	--	--	--	1	--	--	1	5
230	--	--	--	--	--	--	--	--	--
232	--	--	--	1	1	--	--	2	2
234	--	--	--	--	--	--	--	--	--
236	--	1	--	--	--	--	--	1	1
238	--	--	--	--	--	--	--	--	--
240	--	--	--	--	--	--	--	--	1
Totals	--	22	57	65	38	8	--	190	950
Mean lengths	--	197	204	207	207	205	--	205	203

TABLE 10

Length Composition of Year Classes in Sardine Samples from Central Baja California Interseason Catch, 1962

Standard length (mm)	Year class							Totals	
	1961	1960	1959	1958	1957	1956	1955	Aged	Measured
142	--	--	1	--	--	--	--	1	1
144	--	--	--	--	--	--	--	--	1
146	--	--	--	--	--	--	--	--	1
148	--	--	--	--	--	--	--	--	--
150	--	--	--	--	--	--	--	--	3
152	--	--	1	--	--	--	--	1	1
154	--	--	--	--	--	--	--	--	2
156	--	--	1	--	--	--	--	1	4
158	--	--	3	--	--	--	--	3	10
160	--	--	1	--	--	--	--	1	11
162	--	--	--	--	--	--	--	--	24
164	--	1	2	2	1	--	--	6	26
166	--	--	--	3	--	--	--	3	45
168	--	--	3	6	1	--	--	10	42
170	--	1	4	5	1	--	--	11	52
172	--	--	3	4	2	1	--	10	67
174	--	2	5	5	3	--	--	15	82
176	--	--	3	7	4	1	--	15	56
178	--	--	4	6	4	--	--	14	62
180	--	--	1	3	4	--	--	8	47
182	--	--	1	4	3	--	--	8	34
184	--	1	1	2	2	1	--	7	31
186	--	--	2	2	2	2	1	9	25
188	--	--	2	2	--	--	--	4	9
190	--	--	--	--	1	--	--	1	10
192	--	--	--	--	--	--	--	--	1
194	--	--	--	1	1	1	--	3	5
196	--	--	--	--	--	--	--	--	4
198	--	--	--	--	--	--	--	--	3
200	--	--	--	--	1	--	--	1	8
202	--	--	--	1	--	--	--	1	7
204	--	--	--	1	--	--	--	1	2
206	--	--	--	2	1	--	--	3	11
208	--	--	--	1	--	--	--	1	6
210	--	--	--	--	--	--	--	--	1
212	--	--	--	--	--	--	--	--	--
214	--	--	--	--	--	--	--	--	1
216	--	--	--	--	--	1	--	1	2
218	--	--	--	--	--	--	--	--	1
220	--	--	--	--	--	--	--	--	1
222	--	--	--	1	--	--	--	1	1
Totals	--	5	38	58	31	7	1	140	700
Mean lengths	--	173	171	179	180	188	186	177	176

TABLE 11

Year Class Composition of the 1962 Interseason Sardine Catch off Baja California

Lunar month	Catch		Numbers of fish in thousands by year class						
	Tons	Number	1961	1960	1959	1958	1957	1956	1955
"March"*	905	6,672	--	52	601	3,374	2,097	522	26
"April"	2,064	15,655	--	128	1,464	7,965	4,910	1,125	63
"May"	2,344	18,165	--	--	2,638	7,635	5,898	1,994	--
"June"	746	4,971	--	478	2,860	1,392	133	108	--
"July"	--	--	--	--	--	--	--	--	--
"August A"	61	383	--	111	199	65	8	--	--
"August B"†	133	1,024	--	215	604	176	29	--	--
Totals	**‡6,253**	**46,870**	--	**984**	**8,366**	**20,607**	**13,075**	**3,749**	**89**
Percentage		100.00	--	2.10	17.85	43.96	27.90	8.00	.19

* No samples, ages estimated from samples taken in "April".

† Excluding landings September 1–13.

‡ Includes landings from Ensenada and Cedros Island only. No samples were collected from 3,791 tons landed at Puerto Adolfo Lopez Mateos.

TABLE 12

Age and Year Class Composition of the Sardine Catch in the 1962–63 Season

	Catch		Numbers of fish in thousands by age and year class					
			1	2	3	4	5	6
	Tons	Number	1961	1960	1959	1958	1957	1956
Central California								
"August A"[1]	384	1,813	--	73	--	689	725	326
"August B"	424	2,026	--	--	--	790	912	324
"September"	297	1,624	--	--	--	682	715	227
"October"	53	257	--	--	--	116	121	20
"November"[2]	19	93	--	--	--	42	44	7
"December"[2]	16	75	--	--	--	34	35	6
"January"	6	27	6	21	--	--	--	--
Total Central California	**1,199**	**5,915**	**6**	**94**	--	**2,353**	**2,552**	**910**
Percentage		100.00	.10	1.59	--	39.78	43.15	15.38
Southern California								
"August B"[3]	16	87	--	--	42	39	6	--
"September"	240	1,455	--	--	698	655	102	--
"October"	485	2,888	--	--	1,415	982	462	29
"November"	192	1,179	--	--	683	448	24	24
"December"	127	708	--	--	71	524	113	--
"January"	188	1,047	--	--	356	419	220	52
"February"[4]	229	1,173	--	--	317	469	387	--
Total Southern California	**1,477**	**8,537**	--	--	**3,582**	**3,536**	**1,314**	**105**
Percentage		100.00	--	--	41.96	41.42	15.39	1.23
Total California	**2,676**	**14,452**	**6**	**94**	**3,582**	**5,889**	**3,866**	**1,015**
Percentage		100.00	.04	.65	24.79	40.75	26.75	7.02
Baja California								
"August B"	340	2,780	--	749	1,594	5	432	--
"September"	879	7,681	--	1,081	4,384	2,114	68	34
"October"[5]	240	2,139	--	203	809	1,002	--	125
"November"	870	7,114	--	1,646	4,064	1,103	279	22
"December"	828	6,476	--	1,463	2,650	1,634	558	171
"January"[6]	1,297	9,251	--	2,073	4,882	1,813	483	--
"February"	920	6,731	--	1,645	3,702	985	399	--
Total Baja California	**5,374**	**42,172**	--	**8,860**	**22,085**	**8,656**	**2,219**	**352**
Percentage		100.00	--	21.01	52.37	20.53	5.26	.83
Total	**8,050**	**56,624**	**6**	**8,954**	**25,667**	**14,545**	**6,085**	**1,367**
Percentage		100.00	.01	15.81	45.33	25.69	10.75	2.41

[1] August 1–14.

[2] No samples; ages estimated from "October".

[3] September 1–13; no samples; ages estimated from "September".

[4] February 9–March 2.

[5] No samples; ages estimated from "September".

[6] No samples; ages estimated from "February".

[7] Includes landings from Ensenada and Cedros Island only. No samples were collected from 2,756 tons landed at Puerto Adolfo Lopez Mateos.

REFERENCE

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printed in CALIFORNIA OFFICE OF STATE PRINTING

92055—800 3-67 600

Proceedings of the National Shellfisheries Association
Volume 57 — June 1967

INFESTATION OF THE HARD CLAM, *MERCENARIA MERCENARIA*, BY THE BORING POLYCHAETE WORM, *POLYDORA CILIATA*

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ABSTRACT

Accidental and experimental infestation of the hard clam, Mercenaria mercenaria, *by the polychaete worm,* Polydora ciliata, *in the laboratory is described. Experimental infestation was obtained by putting free-swimming larvae of* P. ciliata *in pans with hard clams; here the larvae metamorphosed and built tubes on the clams' shells. Perforation of the shells of clams 5-8 mm long appeared within 18 days but took twice as long in clams 30-35 mm long. Calcified mud blisters appeared on the inner surfaces of the shells of all clams within 30 days after the shells were perforated. Despite considerable damage to the shells of the victims, especially small individuals, chi-square analysis of several groups of data did not consistently show statistically significant differences between the mortality of infested clams and controls.*

Clams in a sand substrate were not attacked by the worms. Several clams that became infested before they burrowed into the sand showed no signs of the worms when examined weeks later. It seems that, by burying, clams escape attack by P. ciliata *but exposed clams, especially small ones, can suffer considerable damage to their shells.*

INTRODUCTION

Several species of polychaete worms of the genus *Polydora*, including *P. ciliata*, have a well-deserved reputation as oyster pests (Korringa, 1952). *Polydora ciliata* have also been noted in other mollusks — for example, the sea mussel, *Mytilus edulis* (Field, 1922, from Lebour, 1907), the periwinkle, *Littorina littorea* (Thorson, 1946), and the bay scallop, *Aequipecten irradians* (Turner and Hanks, 1959). To my knowledge, however, this species has never been reported in the hard clam. The following account describes accidental and experimental infestations of the hard clam by *P. ciliata* in the laboratory.

During a recent winter, we found laboratory-reared clams of various sizes, from 3 to 16 mm long, infested with a species of *Polydora*, identified as *P. ciliata* by Dr. Marian Pettibone, Invertebrate Division, U. S. National Museum. The infested clams were being grown in trays of warmed, running sea water without a substrate into which they could burrow. At the time of the discovery, the infestation was well-established and most affected clams contained the U-shaped external burrows typical of *P. ciliata*. Also present, and covered with new shell material, were the mud-laden tubes of the worms which formed raised areas on the internal faces of the shells (Figs. 1 and 2).

All of the dead individuals from the largest size group (average length 13 mm) contained *P. ciliata*. Eighty-five per cent of the dead clams from the next largest size group (average length 10 mm) were also infested. Only 5 per cent of the dead clams from the 8 mm group contained *P. ciliata* and the worm was completely absent from dead clams of the smallest size group (average length 5 mm). These data suggested that the worm larvae were present in the seawater system, that they began to burrow into the clams soon after the clams were placed in running water and that the highest percentage of infestation was in the largest clams because they had been in running water the longest. It was apparent also that,

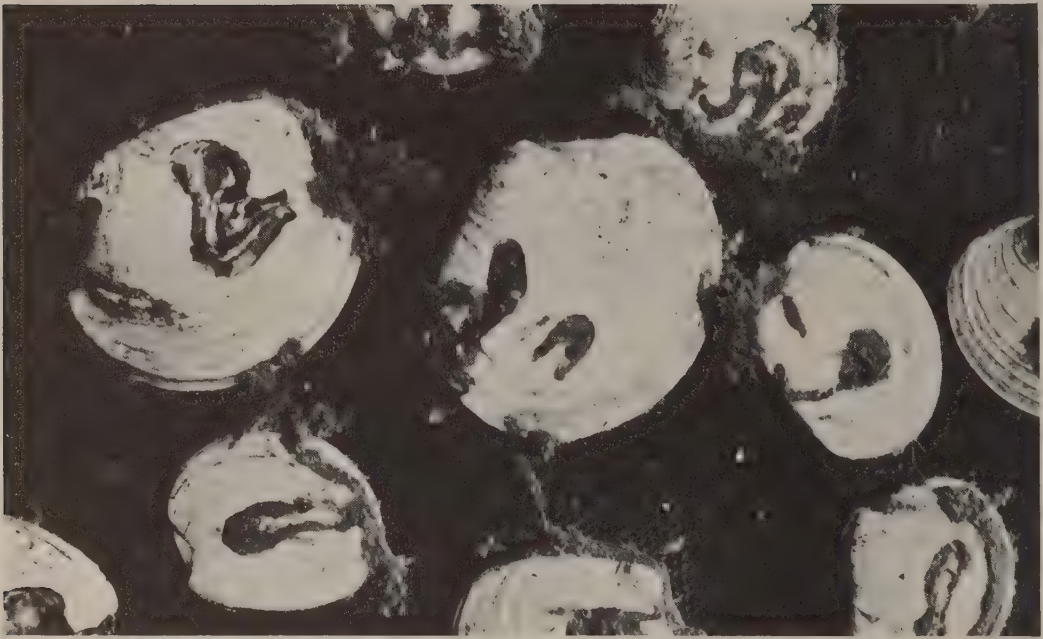

FIG. 1. *Typical U-shaped burrows of* P. ciliata *in live young clams.*

although the activity of the worms in the clams' shells may have contributed to the death of their hosts, many dead clams, especially of the smaller sizes, contained no *P. ciliata* and must have died from other causes.

These observations proved little, except that *P. ciliata* can attack clams. Left unanswered were several questions. How readily and under what circumstances does *P. ciliata* attack clams? What is the rate of penetration of the shell? How is the degree of infestation and damage to the clam related to size of the clam? Does the presence of *P. ciliata* contribute to the mortality of clams?

EXPERIMENTAL INFESTATION OF HARD CLAMS

Within 6 months after they were discovered in the clams, many of the worms became sexually mature and laid eggs. Development of the eggs and larvae followed Wilson's description (1928) for this species. Eggs were deposited in transparent sacs, each attached to the inner wall of the worm's tube by a stalk. There the eggs developed into ciliated larvae which moved about actively within the sacs. At a length of approximately 250 μ, when three setiferous segments had developed, the larvae left the egg sacs and became free-swimming. Contrary to Wilson's experience (1928), I had no trouble obtaining metamorphosis of the larvae and continued growth of the young worms.

Experiment No. 1

In the first attempt to induce experimental infestation, and thus to learn the sequence and timing of the events involved, I added early free-swimming larvae of *P. ciliata* to an enamel pan containing 6 liters of sea water and 100 clams 5 to 10 mm long. A pan of 100 control clams of similar sizes was also maintained. The water was changed 3 times a week. Mixed algae were added daily as food for the clams; it may also have been consumed by the worm larvae. In approximately 20 days, the larvae metamorphosed, constructed tubes on the outer surfaces of many clams, and began to erode the shell immediately under the tube. Within the next 10 days some worms had perforated the shell, stimulating the clams to deposit new shell material to wall off the intrusion. This group of clams was kept under observation 47 days. Erosion and damage

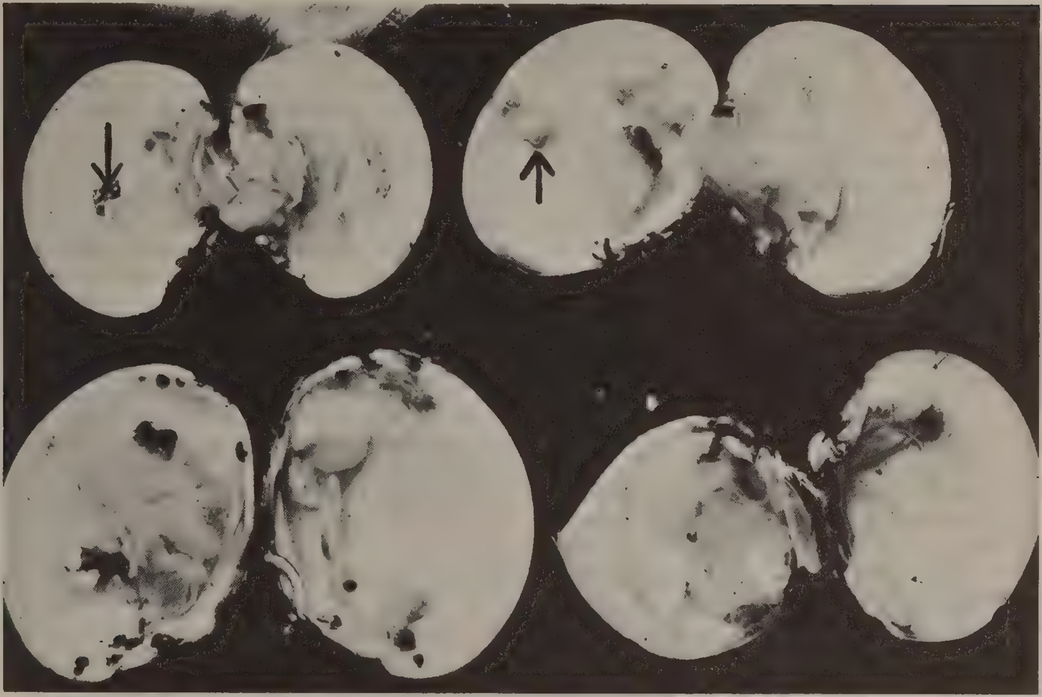

FIG. 2. *Live young clams with shell-covered mud-bubbles caused by* P. ciliata *tubes protruding through the clams' shells.*

to the clams' shells increased steadily; in a few clams the soft parts became visible through the damaged shells. During this period, 17 clams in the pan with *P. ciliata* died; all contained live worms and their muddy, shell-covered tubes. One clam died in the control pan. Chi-square analysis showed the difference in number of dead clams between treated and control groups to be significant at the 95-per cent confidence level.

Experiment No. 2

The second experiment was designed to learn whether *P. ciliata* attacks clams that have dug into the substrate. One hundred clams 5 to 10 mm long were allowed to dig into sand in a 6-liter enamel pan after which early free-swimming larvae of *P. ciliata* were added. A second pan of clams with worm larvae but without sand and a third pan with clams only were included in the experiment. By the fourteenth day worm larvae in the pan without sand had metamorphosed and had built tubes on 30 of the 100 clams. In the pan with sand, worm tubes were present on all of the clams which were still on the surface. Shortly thereafter, these 6 clams dug into the sand.

All of the clams were removed and examined at the end of 2 months. Of those in the pan with worms but no sand, 16 clams had perforated shells and at least one well-calcified mud pocket, each containing a worm. The remaining 84 clams were free of worms. Apparently, some of the worms that had originally set on the 30 clams not only failed to continue their attack but moved away. None of the clams in the pan with sand contained *P. ciliata* at this time and only 5 showed any sign of past infestation. Mortality was negligible in all pans.

Experiment No. 3

This experiment was performed to determine if the rate of infestation by *P. ciliata* or the extent of damage and death was related to the size of the clams. Twenty clams averaging 32 mm long, 100 averaging 8 mm long, and 100 averaging 5 mm long were placed in separate 6-liter pans together with equal numbers of worm larvae. Controls were maintained for each size-group of clams.

Shells of the 5-mm group of clams were perforated within 18 days after the worm tubes appeared; those of the 8-mm group were perforated within 20 days. In the 32-mm group of clams, however, shells were not perforated before the thirty-ninth day. The shell-covered, muddy bulges on the inner faces of the shells were present in all size groups within 30 days after perforation.

Six months later at the end of the experiment all 20 of the clams in the 32-mm group of controls were alive. Seventeen of those exposed to *P. ciliata* were alive and all contained at least 1 live worm, as had the 3 clams which died during this period. Most of the infested clams exhibited both shell perforations and the internal signs of worm activity but the areas of damage were a small part of the total shell area.

Eighty-three clams in the 8-mm control group and 71 clams in the group exposed to worm larvae were still alive at the end of 6 months. Twenty of the exposed clams contained *P. ciliata* or showed signs of former infestation. Those that did contain live worms also contained muddy areas newly-coated with shell material over a considerable part of the inner surface of the shells. The affected clams appeared to be healthy otherwise and siphoned as vigorously as the controls.

Of the smallest clams (5 mm), 84 controls and 71 of the clams exposed to worm larvae were alive when the experiment ended. Thirty-five of the exposed clams contained worms, all of which had internal, recently-calcified, muddy areas occupying more than half of the inner shell surface of the victims. In a few of the affected clams, the soft parts were visible through breaks in the shell caused by the burrowing of the worms. These clams, nevertheless, pumped actively and gave no sign of distress.

In none of the 3 groups of clams was the difference in number of dead clams between exposed and control lots statistically significant at the 95-per cent confidence level, although the chi-square value approaches significance in each group.

ROLE OF *POLYDORA CILIATA* AS AN EPIZOON

Polydora ciliata is known to be a boring species as contrasted to *Polydora websteri*, the common "mud blister worm" in oysters, which apparently is not (Korringa, 1952). Opinions in the literature differ, however, as to whether *P. ciliata* makes mud blisters on the inner surfaces of its hosts' shells. Korringa (1952) stated that *P. ciliata* does not make mud blisters in oysters. It burrows into the shell from the outside and only occasionally perforates it. The oyster seals off the occasional perforations by laying down small amounts of additional shell material which do not form blisters. Turner and Hanks (1959), on the other hand, found "calcified blisters characteristic of *Polydora* along the inner edge of both shells" in the bay scallop, *Aequipecten irradians*. My own observations of *P. ciliata* in clams show that the clams' attempts to seal off the extensive perforations produce large, raised, calcified, soft bubbles immediately over the worms' mud tubes on the inner surfaces of the shells; these structures can accurately be called "blisters".

The experiments reported here show that buried clams are not susceptible to attack by *P. ciliata*. The fact that worms leave infested clams that burrow into the substrate indicates that a subsurface existence is intolerable to *P. ciliata*.

The effect of the burrowing worms in the clams' shells on the well-being of the victims is not entirely clear. Statistical tests of the experimental data are inconclusive as to the significance of the differences between the death rates of clams exposed and those not exposed to *P. ciliata*. It is possible, however, that extensive shell damage, and the energy required to repair it, weakens the victims and may in time make them more susceptible to disease or predation.

ACKNOWLEDGMENTS

Miss Lucretia Reese and Mr. Harry Cook aided in collecting the data for this paper.

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MÉTHODE NOUVELLE D'APPLICATION DU MODÈLE DE SCHAEFER AUX POPULATIONS EXPLOITÉES D'ALBACORES DANS L'ATLANTIQUE

par J.-C. LE GUEN[1] et J.-P. WISE[2]

Résumé

Le modèle mathématique de Schaefer, appliqué à l'étude d'une population de poissons soumise à la pêche, permet d'estimer la droite d'équilibre $U = a+bF$ dans laquelle U représente la prise par unité d'effort et F l'effort de pêche. Nous décrivons une nouvelle méthode d'approche de cette droite d'équilibre faisant intervenir le facteur temps dt *de l'équation :*

$$\frac{dP}{dt} = k_1 \ P(L\text{-}P) - k_2 PF$$

Appliquée aux pêcheries de flétans (halibut) et d'albacores (yellowfin) du Pacifique, cette méthode nous a conduit à des résultats presque identiques à ceux obtenus par Schaefer (1954, 1957). Nous avons de la même façon étudié la pêcherie d'albacores de l'Atlantique, exploitée par les palangriers japonais de 1956 à 1963. Les meilleures conditions d'équilibre seraient obtenues avec un effort de pêche de l'ordre de 15 millions d'hameçons.

Summary

The mathematical model of Schaefer, applied to the study of fish population under exploitation by a fishery, allows to estimate the equation of the line of equilibrium conditions $U = a+bF$ in which

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U is the catch per unit effort and F the fishing effort. We describe here a new method of approach which includes the time factor dt *of the equation:*

$$\frac{dP}{dt} = k_1 \, P(L\text{-}P) - k_2 PF$$

Applied to the halibut and yellowfin Pacific fisheries this method has led us to results almost identical with those of Schaefer (1954, 1957). We have studied the Japanese long line fishery in the Tropical Atlantic from 1956 to 1963. Maximum equilibrium catch for Yellowfin would be obtained by fishing effort of about 15 millions hooks.

Le modèle mathématique employé par M. B. Schaefer (1954) pour étudier la dynamique des populations de Poissons soumises à une pêche commerciale, est comparable au modèle utilisé pour analyser les relations prédateurs-proies (Gause, 1934 ; Lotka, 1925). Il suppose que tous les facteurs d'environnement, excepté la prédation par l'homme c'est-à-dire l'intensité de la pêche, varient de façon aléatoire et peuvent être considérés comme constants, quelle que soit la taille de la population considérée. L'équation de base du modèle de Schaefer est alors l'équation logistique de Verhulst-Pearl

$$\frac{dP}{dt} = k_1 \, P(L - P) \qquad (1)$$

dans laquelle $\frac{dP}{dt}$ représente le taux naturel instantané d'accroissement du stock en l'absence de pêche, P le stock c'est-à-dire l'effectif ou le poids total de la population étudiée, L le stock maximal compatible avec l'espace vital et la quantité de nourriture disponible dans le milieu, et k_1 un coefficient constant. Cette équation logistique a été utilisée avec succès pour décrire la croissance d'une variété considérable d'organismes allant de la mouche des fruits aux humains (Pearl, 1925).

La prise moyenne par unité d'effort de pêche U est proportionnelle à la taille moyenne de la population

$$U = k_2 \, P \qquad (2)$$

et en appelant F l'effort de pêche, $UF = k_2 \, PF$ représente la prédation par l'homme. A chaque instant la croissance de la population pêchée est égale à la croissance naturelle moins la prédation due à la pêche.

$$\frac{dP}{dt} = k_1 \, P(L - P) - k_2 PF \qquad (3)$$

On admet en outre que les changements dans l'intensité de la pêche obéissent à la loi suivante

$$\frac{dF}{dt} = k_3 \, F(P - b) \qquad (4)$$

Dans cette équation, k_3 est une constante et b représente le « niveau économique du stock » tel que le coût des opérations de pêche soit égal aux bénéfices ; dF ayant le signe de $(P - b)$, quand le stock diminue au point de dépasser son niveau économique, dF devient négatif c'est-à-dire que l'effort de pêche décroît : les pêcheurs n'étant plus intéressés tendent à déserter les lieux de pêche.

En l'absence de toute régulation imposée par l'homme, la relation entre P et F est obtenue en divisant l'une par l'autre les équations (3) et (4)

$$\frac{dP}{dF} = \frac{k_1 P(L - P) - k_2 PF}{k_3 \, F(P - b)} \qquad (5)$$

D'après Lotka (1923), la courbe représentative de $P = \psi(F)$ est alors une spirale qui s'enroule autour d'un pôle asymptotique ayant pour coordonnées

$$F = \frac{k_1}{k_2}(L - b) \text{ et } P = b \qquad \text{(Fig 1.)}$$

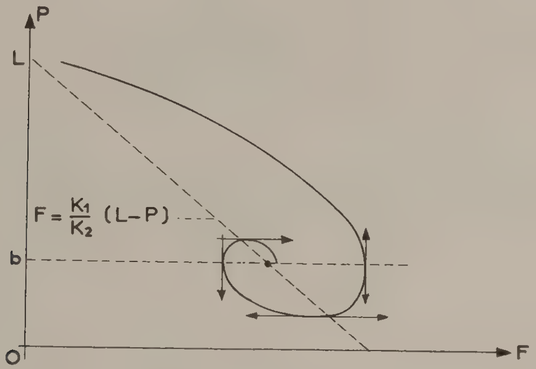

Fig. 1. — Relation entre le stock P, en ordonnées, et l'effort de pêche F, en abscisses. En traits interrompus, lieu des tangentes horizontales et verticales.

Le lieu des tangentes horizontales est défini par l'équation $\frac{dP}{dF} = O$, c'est donc la droite

$$F = \frac{k_1}{k_2}(L - P)$$

Le lieu des tangentes verticales est défini par l'équation $\frac{dP}{dF} = \infty$, c'est donc la droite horizontale

$$P = b$$

P oscille au-dessus et au-dessous du niveau $P = b$, les oscillations devenant de plus en plus amorties. F oscille de façon semblable autour de la valeur $F = \frac{k_1}{k_2}(L - b)$. Mais en réalité le niveau économique pouvant varier d'année en année, le lieu des tangentes verticales n'est pas fixe. Par contre la droite lieu des tangentes horizontales, est indépendante de la valeur de b. Cette droite définie par l'équation $F = \frac{k_1}{k_2}(L - P)$ sera appelée « droite d'équilibre » (line of equilibrium conditions de Schaefer). En effet, lorsque la régulation par l'homme s'effectue en imposant une valeur donnée à l'effort de pêche F, elle représente le lieu des conditions d'équilibre entre F et P.

Dans la pratique, il est intéressant de faire apparaître la prise par unité d'effort U. Pour cela il suffit de remplacer P par $\frac{U}{k_2}$. L'équation de la droite d'équilibre devient alors

$$F = \frac{k_1}{k_2^2}(L_u - U) \qquad (6)$$

dans laquelle $L_u = k_2 L$ est la prise par unité d'effort correspondant au stock maximal L. Dans la suite de l'exposé, le niveau du stock sera défini par la valeur U et non plus par P.

Le but de la dynamique des populations est de déterminer l'équation (6) de la droite d'équilibre. Schaefer a décrit pour cela deux méthodes. La première (Schaefer, 1954) nécessite la connaissance du coefficient k_2, obtenu par une étude préliminaire de la mortalité f due à la pêche. On a en effet

$$f = 1\text{-}e^{-Fk_2} \text{ (Gulland, 1964)}$$

La seconde méthode (Schaefer, 1957) est basée sur l'étude des variations $\Delta\overline{U_i}$ de la prise par unité d'effort durant l'année i, variations estimées égales à

$$\Delta\overline{U_i} = \frac{\overline{U_{i+1}} - \overline{U_{i-1}}}{2}$$

Cette méthode plus approximative que la première ne fait pas intervenir le facteur constant k_2. L'équation de la droite d'équilibre est estimée à partir des statistiques annuelles de débarquements des pêcheries, en calculant pour chaque année l'effort total de pêche F et la prise moyenne par unité d'effort $\overline{U}$.

Nous nous proposons de décrire une troisième méthode d'estimation de l'équation de la droite d'équilibre à partir des mêmes statistiques de débarquements, c'est-à-dire à partir des valeurs annuelles de F et $\overline{U}$, en faisant intervenir le facteur temps qui disparaît dans l'équation générale (5) de Schaefer obtenue en divisant $\frac{dU}{dt}$ par $\frac{dF}{dt}$. Nous supposons que l'effort de pêche F, appliqué pendant une année à une population U, entraîne une variation ΔU conduisant à un état d'équilibre entre F et U au bout d'un temps Δt. Cet état d'équilibre peut être atteint soit l'année même où l'effort de pêche F est appliqué, soit au cours des années suivantes. Ne disposant que des valeurs annuelles pour U et F, il nous est impossible de connaître les valeurs exactes de ΔU et Δt et nous pouvons seulement calculer les variations $\Delta\overline{U_n}$ observées au bout d'un nombre entier d'années, $\Delta t = 0, 1, 2, 3...$ etc.

Supposons que la variation ΔU se fasse sentir l'année même où l'effort F est appliqué. Quelle que soit l'année n, on aura toujours $\Delta\overline{U_n} \simeq 0$. L'ensemble des points $(\overline{U_n}, F_n)$ se trouvera donc au voisinage de la droite d'équilibre pour laquelle $\frac{dU}{dt} = 0$. Toute droite d'ajustement représentant l'ensemble des points $(\overline{U_n}, F_n)$ pourra être considérée comme une estimation de la droite d'équilibre cherchée.

Si, par contre, la variation se fait seulement sentir dans le courant de la xième année suivant l'application de l'effort F, la valeur la plus proche de celle du stock $\overline{U_n} + \Delta\overline{U_n}$ que nous puissions connaître sera $\overline{U_{n+x}}$. D'où

$$\Delta\overline{U_n} = \overline{U_{n+x}} - \overline{U_n}$$

Dans ce cas, ce sont les points $(\overline{U_{n+x}}, F_n)$ qui sont les plus voisins de la droite d'équilibre et toute droite d'ajustement représentant l'ensemble de ces points pourra être considérée comme une estimation de la droite d'équilibre cherchée.

Si l'on connaissait x, on pourrait obtenir une première estimation à partir de l'ensemble des valeurs annuelles $\overline{U_n}$ et Fn en associant, pour chaque valeur de n, $\overline{U_{n+x}}$ et F_n. Mais en général x est inconnu ; tout ce que nous pouvons dire c'est que, si notre hypothèse de travail est fondée et notre méthode valable, les points $(\overline{U_{n+x}}, F_n)$ seront plus près de la position d'équilibre, c'est-à-dire mieux alignés que les points $(\overline{U_n}, Fn)$, $(\overline{U_{n+1}}, F_n)$, etc.

On calculera donc les différents coefficients de corrélation entre les groupes successifs de variables

$$\begin{array}{ll} \overline{U_n} & \text{et } F_n \\ \overline{U_{n+1}} & \text{et } F_n \\ \dots\dots\dots\dots & \\ \overline{U_{n+x}} & \text{et } F_n \\ \dots\dots\dots\dots & \end{array}$$

et on cherchera pour quelle valeur de x on obtient la meilleure corrélation c'est-à-dire le meilleur alignement. Enfin on remarquera que $\overline{U_o}$, prise maximale par unité d'effort au début de l'exploitation du stock, n'est autre que l'ordonnée du point où la droite d'équilibre coupe l'axe des U. En effet, l'équation (6) montre que si $F = O$, on a alors $\overline{U_o} = L_u$. L'estimation de la droite d'équilibre devra donc passer au voisinage du point ($\overline{U_o}$, O). La figure 2 montre la position des points théoriques pour les quatre cas où Δt prend les valeurs entières 0, 1, 2 et 3. On voit immédiatement que les points ($\overline{U_n}$, F_n) sont d'autant plus éloignés de la position d'équilibre que Δt est plus grand. On note également que si $\Delta t = x$, on a $\overline{U_o} = \overline{U_1} = \overline{U_2} \dots = \overline{U_x}$, c'est-à-dire que les prises par unité d'effort restent stables à leur niveau maximal durant les x premières années d'exploitation du stock.

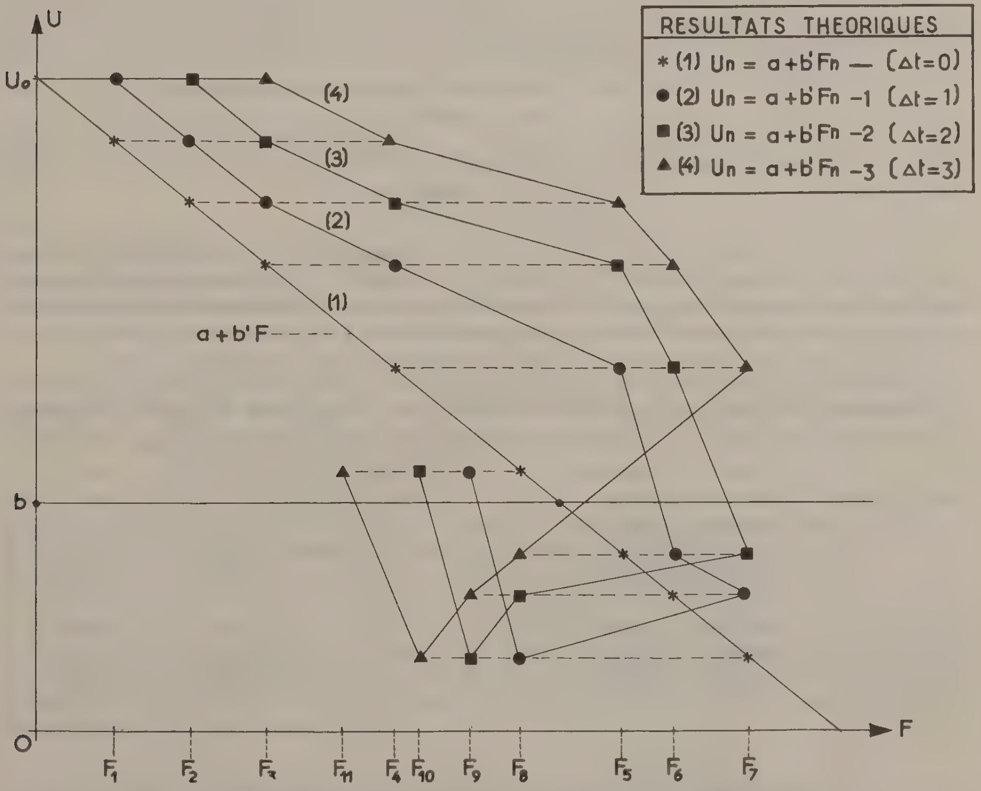
RESULTATS THEORIQUES
* (1) Un = a+b'Fn — (Δt=0)
● (2) Un = a+b'Fn -1 (Δt=1)
■ (3) Un = a+b'Fn -2 (Δt=2)
▲ (4) Un = a+b'Fn -3 (Δt=3)
U
U₀
b
O
F
(1)
(2)
(3)
(4)
a+b'F
F1
F2
F3
F11
F4
F10
F9
F8
F5
F6
F7

Fig. 2. — Situation des points (U, F) lorsque $\Delta t = 0, 1, 2, 3$. U, en ordonnées, représente le stock ; F_1, ... F_{11}, en abscisses, représentent les efforts de pêche de 11 années successives.

Exemple 1. — Schaefer (1954) a étudié la population de flétans (halibut) du Pacifique *(Hippoglossus stenolepis)* dans la région sud du Cap Spencer. L'effort de pêche était exprimé en paniers (skates) et la prise par unité d'effort en livres (pounds) et l'équation de la droite d'équilibre, obtenue à partir de la détermination préalable de k_2 était : $U = 156{,}1 - 0{,}00021\ F$.

Reprenant les mêmes données et les mêmes unités, nous avons calculé les équations des droites de régression de U en F, à partir des points $(\overline{U_{n+x}}, F_n)$ pour x variant de 0 à 4. A la suite de chaque équation, nous donnons le nombre N de points utilisés, le coefficient de corrélation R entre F et U et l'écart-type SD obtenu à partir de la meilleure estimation de la variance liée (1).

Les résultats suivants ont été obtenus :

x	Droite de régression	N	R	SD
0	$U = 146{,}3 - 0{,}00019\ F$	33	-0,795	11,8
1	$U = 133{,}3 - 0{,}00016\ F$	32	-0,795	10,7
2	$U = 125{,}3 - 0{,}00014\ F$	31	-0,835	8,4
3	$U = 115{,}3 - 0{,}00012\ F$	30	-0,690	11,1
4	$U = 96{,}4 - 0{,}00008\ F$	29	-0,478	12,5

Nous savons que dans les débuts de la pêcherie la prise par unité d'effort était nettement supérieure à 146,3. Les valeurs de U_o figurant dans les équations des droites de régression pour $x = 1, 2, 3, 4$ sont donc trop faibles et nous sommes conduits à choisir comme estimation de la droite d'équilibre la droite de régression correspondant à $x = 0$. Son équation est

$$U = 146{,}3 - 0{,}00019\ F$$

cette équation étant très voisine de celle trouvée par Schaefer

$$U = 156{,}1 - 0{,}00021\ F$$

Exemple 2. — Schaefer (1957) a étudié la population d'albacores ou yellowfin *(Thunnus macropterus)* du Pacifique Tropical Est, à partir des statistiques de débarquements, sans faire intervenir cette fois le coefficient k_2. L'unité d'effort de pêche était égale à quatre jours standard de pêche et la prise par unité d'effort était exprimée en livres. L'équation obtenue était :

$$U = 11\,246 - 0{,}16384\ F$$

Reprenant les mêmes données et les mêmes unités, nous avons obtenu les résultats suivants :

x	Droite de régression	N	R	SD
0	$11\,356 - 0{,}16586\ F$	22	-0,775	1347
1	$10\,853 - 0{,}14026\ F$	21	-0,689	1544
2	$10\,627 - 0{,}13529\ F$	20	-0,675	1573
3	$10\,703 - 0{,}16102\ F$	19	-0,725	1468
4	$10\,699 - 0{,}18362\ F$	18	-0,757	1390
5	$10\,469 - 0{,}17534\ F$	17	-0,725	1467

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(1) La droite de régression de U en F est telle que la somme des carrés des distances des points observés à la droite, Σd^2, soit minimale. Cette valeur minimale est égale à $N\sigma^2_F\,(1-R^2)$, avec 2 degrés de liberté. La meilleure estimation de la variance correspondante, dite variance liée, est donc $\frac{N\sigma^2_F\,(1-R^2)}{N-2}$.

Dans les données dont nous disposions, la meilleure prise moyenne annuelle $\overline{U}$ était de 11 571 livres en 1936. Ici encore nous choisirons comme estimation de la droite d'équilibre la droite de régression obtenue pour $x = 0$ et dont l'équation est

$$U = 11\,356 - 0{,}16586\ F$$

très voisine de celle trouvée par Schaefer.

Il est à remarquer que les droites de régression obtenues pour $x = 1, 2, \ldots 5$ sont toutes très voisines les unes des autres et que les coefficients de corrélation sont tous très élevés. Ceci permet de comprendre les résultats auxquels était arrivé J. A. Gulland (1961) dans un travail sur la pêche en Islande. Cet auteur avait, pour la première fois, émis l'hypothèse d'une relation entre l'état d'une pêcherie une année donnée et l'effort de pêche durant les trois années précédentes. Pour voir s'il en est bien ainsi pour la pêcherie d'albacores du Pacifique, nous avons étudié la corrélation entre $\overline{U_n}$ et $F' = \frac{F_n + F_{n-1} + F_{n-2}}{3}$. La droite de régression a pour équation :

$$U = 11\,229 - 0{,}16783\ F'$$

avec $N = 20$, $R = -0{,}761$ et $SD = 1383$.

Nous avons de même étudié la corrélation entre $\overline{U_n}$ et $F' = \frac{F_{n-1} + F_{n-2} + F_{n-3}}{3}$. L'équation de la droite de régression est :

$$U = 11\,019 - 0{,}16489\ F'$$

avec $N = 20$, $R = -0{,}726$ et $SD = 1484$.

Entre $\overline{U_n}$ et $F' = \frac{F_{n-2} + F_{n-3} + F_{n-4}}{3}$ l'équation de la droite de régression est :

$$U = 10\,844 - 0{,}17302\ F'$$

avec $N = 20$, $R = -0{,}722$ et $SD = 1465$.

Ces dernières équations sont très voisines et très semblables à l'équation de la droite d'équilibre obtenue précédemment.

Les données utilisées par Schaefer en 1957 et que nous avons reprises intégralement, couvraient la période 1935-1954. Or nous disposons actuellement des données couvrant la période 1954-1965 (1). A partir de l'ensemble de ces données, et si l'on admet $\Delta t = 0$ comme plus haut, la droite de régression des points $(\overline{U_n}, F_n)$ a pour équation :

$$U = 11\,254 - 0{,}16645\ F$$

avec $N = 32$, $R = -0{,}858$ et $SD = 1267$. Le coefficient de corrélation est encore plus élevé que tous ceux trouvés précédemment et la droite de régression est extrêmement voisine de la droite d'équilibre estimée par Schaefer et qui avait pour équation $U = 11\,246 - 0{,}16384\ F$.

Notre méthode d'estimation de la droite d'équilibre qui tient compte de la meilleure corrélation et de la meilleure évaluation de U_o, conduit donc à des résultats équivalents à ceux obtenus par la méthode de Schaefer. Elle doit se montrer particulièrement précise pour l'étude d'une pêcherie à ses débuts, comme c'est le cas dans l'exemple suivant, car on possède alors une meilleure connaissance de la vraie valeur de U_o.

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(1) Ces données sont disponibles à l'Inter-American Tropical Tuna Commission.

Exemple 3. — Étude de la pêche de l'albacore de l'Atlantique *(Thunnus albacares)* par les palangriers japonais. Cette pêche a débuté après une première campagne de prospection effectuée au large de l'Amérique du Sud en décembre 1955 et de nombreuses campagnes fructueuses dans tout l'Atlantique tropical en 1956. Mais la pêcherie industrielle ne s'est réellement installée qu'en 1957 (Shomura, 1966). Des statistiques détaillées ont été récemment publiées par Shiohama, Myojin et Sakamoto (1965) ainsi que par la « Fisheries Agency of Japan » (1966). Ces statistiques ne couvrent pas toutes les marées effectuées, comme on peut le constater dans le tableau suivant :

Année	Nombre total de marées	Nombre de marées couvertes par les statistiques
1956	4	4 soit 100 %
1957	60	52 — 87 %
1958	131	51 — 39 %
1959	189	96 — 51 %
1960	243	181 — 74 %
1961	258	204 — 79 %
1962	331	196 — 59 %
1963	368	230 — 63 %

Dans la suite, nous admettrons que les données dont nous disposons, effort, prise et distribution géographique, sont représentatives pour toute la flotte de pêche.

Dans un travail présenté au Symposium sur l'Océanographie et les ressources halieutiques de l'Atlantique tropical, tenu à Abidjan en octobre 1966, nous avions divisé l'Atlantique tropical en dix aires, tenant compte dans le mesure du possible des facteurs écologiques et des différentes

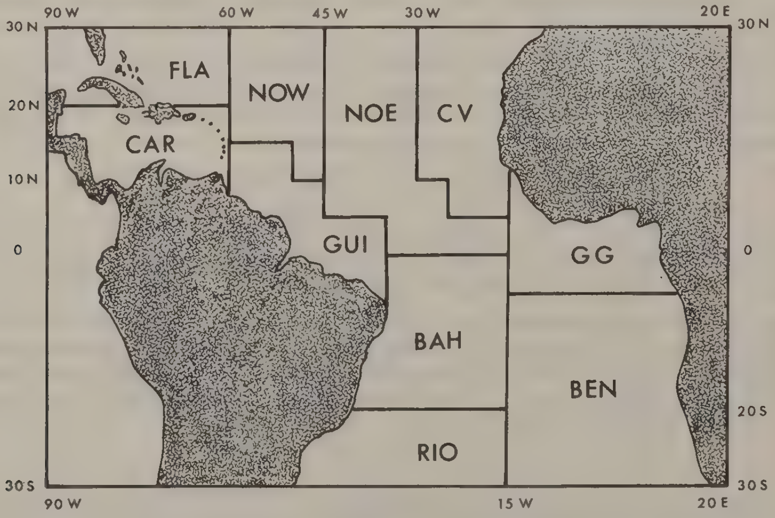

Fig. 3. — Limites des aires de pêche utilisées dans l'étude de la pêche de l'albacore.

concentrations de l'effort de pêche. Les noms de ces aires, dont les limites sont représentées sur la figure 3, ont été abrégés de la façon suivante :

Floride	FLA	Guyanes	GUI
Zone océanique Nord-Ouest	NOW	Golfe de Guinée	GG
Zone océanique Nord-Est	NOE	Bahia	BAH
Cap-Vert	CV	Benguela	BEN
Caraïbes	CAR	Rio de Janeiro	RIO

D'une étude d'ensemble de la pêche par les palangriers (Wise et Le Guen, 1966), il ressort que six de ces aires, GG, CV, NOE, NOW, GUI et CAR, peuvent être considérées comme des aires de pêche à l'albacore. La capture de ce poisson y est en effet l'objectif essentiel des pêcheurs et les prises d'autres espèces peuvent y être considérées comme occasionnelles. Dans les deux aires BAH et BEN, la pêcherie est mixte, les navires passant au cours de l'année des concentrations d'albacores à celles de germons. Enfin dans les deux dernières aires, FLA et RIO, l'albacore constitue une partie négligeable des prises.

L'étude qui suit se borne à l'ensemble des 6 aires à albacores précédemment définies. Pour chacune d'elles, nous disposons des valeurs des efforts de pêche annuels en milliers d'hameçons et des prises moyennes annuelles par unité d'effort en nombre de poissons pris pour 1000 hameçons (voir annexes, tables 1 et 2). En plus des 6 aires précédentes prises isolément, nous avons également considéré les groupements de 2 ou 3 aires contiguës ainsi que la totalité des 6 aires. Pour ces 7 nouvelles aires (GUI+CAR), (NOE+NOW), (GG+CV), (GG+CV+NOE), (NOE+GUI), (CV+NOE) et (GUI+CAR+NOE+NOW+GG+CV), les efforts de pêche annuels peuvent être directement tirés de la table 1. Quant aux prises moyennes annuelles par unité d'effort, elles figurent en annexe (table 3).

Pour chacune des 6 aires prises isolément et pour les 7 nouvelles aires définies précédemment nous avons calculé les coefficients de corrélation entre $\overline{\text{U}}$, prise moyenne annuelle par unité d'effort, et F-x, effort de pêche x années plus tôt (x = 0, 1, 2, 3, 4). Les résultats sont groupés dans le tableau suivant :

AIRES	COEFFICIENTS DE CORRÉLATION				
	U-F	U-F$_{-1}$	U-F$_{-2}$	U-F$_{-3}$	U-F$_{-4}$
GG	-0,72	-0,83	-0,87	-0,89	-0,91
GUI	-0,40	-0,71	-0,60	-0,81	-0,68
NOE	-0,82	-0,71	-0,90	-0,90	-0,78
CV	-0,77	-0,90	-0,97	-0,84	-0,67
CAR	-0,22	-0,27	-0,83	-0,54	-0,32
NOW	-0,67	-0,60	-0,82	-0,78	-0,65
GUI+CAR	-0,30	-0,61	-0,69	-0,84	-0,63
NOE+NOW	-0,81	-0,71	-0,90	-0,90	-0,80
GG+CV	-0,81	-0,93	-0,94	-0,91	-0,85
GG+CV+NOE	-0,91	-0,91	-0,96	-0,95	-0,87
NOE+GUI	-0,69	-0,72	-0,81	-0,85	-0,84
CV+NOE	-0,87	-0,84	-0,96	-0,90	-0,76
Ensemble des 6 aires	-0,90	-0,87	-0,95	-0,97	-0,89

On constate que les meilleures corrélations sont celles entre U et F_{-2} ou F_{-3}. D'ailleurs les tables 2 et 3 figurant en annexe montrent aussi que le déclin de la pêcherie n'est observable que la troisième ou la quatrième année suivant le début de son exploitation. Nous admettrons donc que Δt est compris entre 2 et 3. A titre de vérification nous avons également calculé les coefficients de corrélation entre U et $F' = \frac{F_{-x}+F_{-(x+1)}}{2}$ et entre U et $F' = \frac{F_{-x}+F_{-(x+1)}+F_{-(x+2)}}{3}$ pour $x = 0$, 1, 2 et 3.

Les meilleures corrélations sont obtenues entre U et $\frac{F_{-2}+F_{-3}}{2}$ d'une part et entre U et $\frac{F_{-1}+F_{-2}+F_{-3}}{3}$ d'autre part.

En fait, l'ensemble des données que nous possédons actuellement sur la pêche à l'albacore dans l'Atlantique tropical nous a conduit à grouper les six aires en trois zones seulement, une zone ouest (GUI+CAR), une zone centrale (NOE+NOW) et une zone est (CV+GG). Pour chacune de ces zones nous choisirons entre les deux droites de régression de U en F_{-2} et F_{-3} celle qui correspond au meilleur coefficient de corrélation. La droite ainsi choisie sera considérée comme la droite d'équilibre $U = a+bF$.

La prise équilibrée, en nombre de poissons, sera alors :

$$C = F.U = aF+bF^2$$

et la prise maximale équilibrée C_m est obtenue lorsque $F_m = -\frac{a}{2b}$ en milliers d'hameçons.

Pour la zone ouest (GUI+CAR), la droite d'équilibre estimée, $U = a+bF_{-3}$, a pour équation :

$$U = 64{,}4615 - 0{,}011892\ F$$

avec $N = 8$, $R = -0{,}843$ et $SD = 12{,}0385$.

$F_{mO} = 2710 \pm 506$ et $C_{mO} = 87343 \pm 16308$.

Pour la zone est (GG+CV), la droite d'équilibre estimée, $U = a+bF_{-2}$ a pour équation :

$$U = 100{,}4063 - 0{,}0067995\ F$$

avec $N = 7$, $R = -0{,}945$ et $SD = 12{,}0025$.

$F_{mE} = 7383 \pm 882$ et $C_{mE} = 370648 \pm 44279$.

Pour la zone centrale (NOE+NOW), nous avons deux droites d'équilibre estimées possibles, $U = a+bF_{-2}$ et $U = a+bF_{-3}$, ayant pour équations :

$$U = 84{,}2790 - 0{,}020966\ F$$

avec $N = 8$, $R = -0{,}908$ et $SD = 14{,}4499$.

$$U = 77{,}0879 - 0{,}020262\ F$$

avec $N = 8$, $R = -0{,}908$ et $SD = 14{,}4431$.

Comme estimation de l'effort de pêche F_{mC} correspondant à la prise maximale équilibrée, nous prendrons la moyenne des deux efforts calculés à partir de chacune des droites précédentes ; nous ferons de même pour C_{mC}. On trouve : $F_{mC} = 1955 \pm 350$ et $C_{mC} = 78994 \pm 14119$.

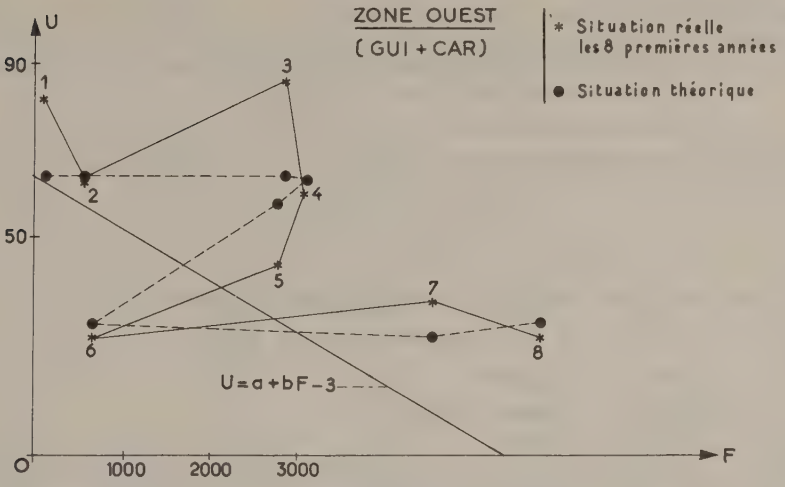

Fig. 4. — Évolution de la pêcherie au cours des 8 premières années. En ordonnées, nombres de poissons pour 1 000 hameçons ; en abscisses, efforts de pêche en milliers d'hameçons.

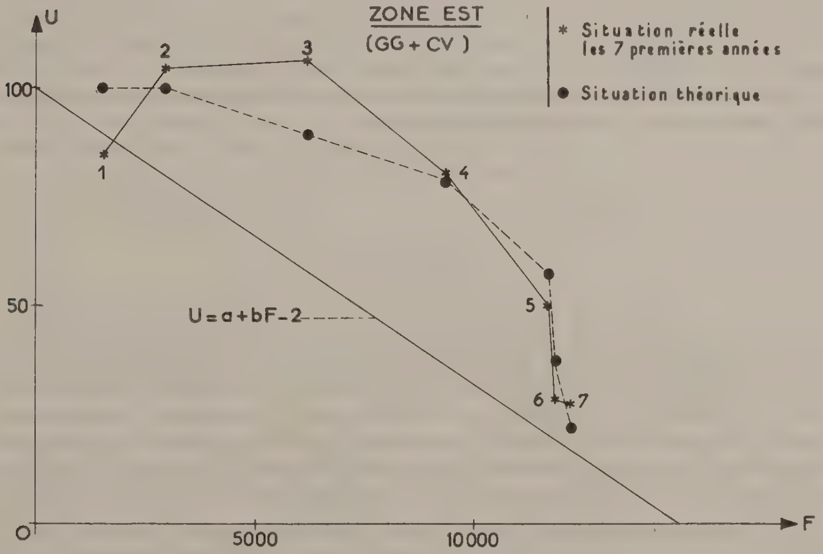

Fig. 5. — Évolution de la pêcherie au cours des 7 premières années. En ordonnées, nombres de poissons pour 1 000 hameçons ; en abscisses, efforts de pêche en milliers d'hameçons.

Les figures 4 et 5 représentent l'évolution de la pêcherie dans les zones ouest et est. Les points théoriques obtenus à partir des lois $U = a+bF_{-3}$ pour la zone ouest et $U = a+bF_{-2}$ pour la zone est, ont été portés sur ces figures, ainsi que les droites d'équilibre. Les points observés sont suffisamment voisins des points théoriques pour que l'on admette la validité des lois de corrélation précédentes.

Pour l'ensemble des 6 aires à albacores on obtient :

$$F_m = F_{mO}+F_{mE}+F_{mC} = 12048 \pm 1738$$
$$C_m = C_{mO}+C_{mE}+C_{mC} = 536985 \pm 74706.$$

Sachant que Δl est compris entre 2 et 3, on peut espérer obtenir un résultat voisin du précédent en considérant l'ensemble des 6 aires et en prenant comme estimation de la droite d'équilibre la droite de régression

$$U = a+b\,\frac{F_{-1}+F_{-2}+F_{-3}}{3}$$

Cette méthode, qui est celle de Gulland, conduit aux résultats suivants :

$$U = 92{,}5398 - 0{,}003892\ F$$

avec $N = 8$, $R = -0{,}957$ et $SD = 9{,}2019$.

$F_m = 11888 \pm 1182$ et $C_m = 550056 \pm 54691$.

En première approximation, on peut donc penser que l'effort de pêche, pour les aires à albacores, devrait être maintenu aux environs de 12 millions d'hameçons, ce qui donnerait une prise maximale équilibrée de l'ordre de 550 000 poissons.

Les prises dans les aires BEN et BAH, dont nous n'avons pas tenu compte jusqu'à présent, ont représenté, de 1957 à 1963, 16 % du total capturé dans les 6 aires à albacores. En 1963, ce pourcentage atteignait 23 %. Les prises dans les zones FLA et RIO ont toujours été minimes. Si l'on estime à 23 % la partie du stock extérieure aux 6 aires à albacores, les valeurs de F_m et C_m précédemment trouvées sont à multiplier par 1,3 pour avoir une idée des conditions optimales d'équilibre entre l'effort de pêche et la prise annuelle pour l'ensemble du stock d'albacores de l'Atlantique tropical. Pour un effort de l'ordre de 15 millions d'hameçons, on aurait alors une prise maximale équilibrée de l'ordre de 715 000 poissons.

Conclusions

On sait que la pêche modifie le stock par prélèvements de poissons. Mais à cet effet qui se fait sentir à court terme dans une pêcherie peut s'ajouter une diminution observable à plus long terme et explicable de deux manières :

— plus l'intensité de pêche est forte une année donnée et plus la longueur moyenne et le poids des poissons capturés sont faibles (Beverton et Holt, 1957) ; les poissons prélevés auraient pu donner leur rendement maximal en poids x années plus tard ;

— s'il existe une relation entre l'état du stock reproducteur et le recrutement, il est possible qu'une forte diminution du stock une année donnée entraîne une importante diminution du recrutement dans la pêcherie x années plus tard.
Suivant l'importance relative de l'effet à court ou à long terme, on obtient pour Δl une valeur proche de 0 ou de x.

Dans l'étude des albacores de l'Atlantique, la prise par unité d'effort a été exprimée en nombre de poissons. Du fait que Δl a été trouvé compris entre 2 et 3, on peut déduire que l'effet à long terme est prépondérant. On ne peut l'expliquer que par une diminution du stock par le recrutement : les prélèvements importants effectués sur le stock encore inexploité se sont traduits par une diminution du recrutement x années plus tard.

Considérant uniquement les premières années d'exploitation de la pêcherie, il était très intéressant de calculer les coefficients de corrélation entre la prise moyenne annuelle par unité d'effort et la prise effectuée les années précédentes. Les résultats figurent dans le tableau suivant :

AIRES	COEFFICIENTS DE CORRÉLATION				
	$\overline{U}$-C	$\overline{U}$-C_{-1}	$\overline{U}$-C_{-2}	$\overline{U}$-C_{-3}	$\overline{U}$-C_{-4}
GG	-0,19	-0,46	-0,88	-0,93	-0,90
CV	-0,27	-0,42	-0,85	-0,87	-0,65
GUI	-0,23	-0,45	-0,47	-0,73	-0,62
NOE	-0,38	-0,55	-0,73	-0,91	-0,83
CAR	-0,14	-0,11	-0,61	-0,51	-0,39
NOW	-0,34	-0,62	-0,54	-0,77	-0,63
GUI+CAR	-0,08	-0,45	-0,59	-0,78	-0,58
GG+CV+NOE	-0,19	-0,58	-0,89	-0,97	-0,87
Ensemble des 6 aires	-0,24	-0,56	-0,84	-0,97	-0,89

Les bonnes corrélations trouvées plus haut entre $\overline{U}$ et F_{-2} ou F_{-3} sont confirmées par celles obtenues entre $\overline{U}$ et C_{-2} et surtout $\overline{U}$ et C_{-3}.

Les valeurs Δt obtenues pour les albacores du Pacifique et de l'Atlantique diffèrent pour de multiples raisons. Les méthodes de pêche, appât vivant dans un cas, palangres dans l'autre, entraînent un âge au recrutement différent. De plus les prises par unité d'effort sont exprimées dans le premier cas en poids et dans le second en nombre de poissons. Enfin le stade d'évolution des pêcheries n'est pas le même. Les premières données dans le Pacifique ont été récoltées alors que la pêcherie existait depuis longtemps déjà : ces données traduisent une situation où les oscillations $\Delta\overline{U}$ et ΔF sont relativement amorties. Les variations $\overline{\Delta U}_n$ sont difficilement discernables et les points (F_n, U_n), (F_{n-x}, U_n) voisins les uns des autres sont également voisins de la droite d'équilibre.

Dans l'Atlantique au contraire, les données récoltées à la naissance de la pêcherie ne couvrent que ses huit premières années d'existence. Les variations $\Delta\overline{U}$ et ΔF sont alors maximales et les points (F_n, U_n) très éloignés de la droite d'équilibre. Dans ces conditions les pêcheurs obtiennent des résultats largement supérieurs à ceux compatibles avec les conditions d'équilibre.

La prise maximale équilibrée C_m que nous avons estimée dans l'Atlantique pour les albacores est la prise maximale en nombre de poissons. La valeur F_m correspondante n'aboutirait pas forcément à une prise maximale équilibrée en poids. Toutefois les conclusions de cette étude sont telles que toute régulation aurait pour but de diminuer l'effort de pêche consacré à l'albacore. Une telle diminution entraînerait forcément une augmentation de la longueur moyenne des captures et se traduirait finalement par un gain en poids.

Remerciements

Nous tenons à remercier MM. M. B. Schaefer, professeur à la Scripps Institution of Oceanography, La Jolla et J. Daget, directeur de Recherches à l' O.R.S.T.O.M., Paris, pour l'aide qu'ils nous ont apportée dans la rédaction de ce travail. Nous remercions également G. Ranallo et J. Schilz qui nous ont assistés dans le dépouillement et la présentation des données.

ANNEXE

TABLE 1

Efforts de pêche annuels en milliers d'hameçons

ANNÉE	GG	GUI	NOE	CV	CAR	NOW
1956	0	82	31	0	0	0
1957	1327	515	1218	234	5	1
1958	1799	2633	1627	1228	288	25
1959	2985	2822	3362	3293	257	91
1960	5004	2465	2914	4444	332	142
1961	7486	550	2102	4238	91	89
1962	5966	3231	9007	5834	1363	1780
1963	6476	3303	8059	5728	2553	3135

TABLE 2

Prise par unité d'effort (moyennes annuelles) en nombre de poissons pour 1 000 hameçons.

ANNÉE	GG	GUI	NOE	CV	CAR	NOW
1956	—	97	101	—	—	—
1957	86	66	73	80	—	—
1958	120	93	88	82	127	45
1959	122	59	62	95	72	55
1960	99	48	47	62	17	55
1961	64	34	29	27	19	9
1962	38	40	19	21	26	19
1963	33	20	17	23	39	5

TABLE 3

Prise par unité d'effort (moyennes annuelles) en nombre de poissons pour 1 000 hameçons

ANNÉE	GUI+CAR	NOE+NOW	GG+CV	GG+CV +NOE	NOE+GUI	CV+NOE	Ensemble des 6 aires
1956	97	101	—	101	98	101	98
1957	64	73	85	80	70	74	77
1958	87	87	105	99	85	85	94
1959	60	62	107	91	60	78	84
1960	43	48	81	73	47	56	68
1961	27	28	50	47	29	27	46
1962	36	19	29	25	24	19	26
1963	28	14	28	24	18	19	23

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Reprinted from JOURNAL OF INVERTEBRATE PATHOLOGY, Vol. 9, No. 2, June 1967
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Frozen-Section Technique in Shellfish Research

Various frozen-section techniques for quick preparation of vertebrate tissues are well known. Similar techniques are required for rapid pathological examination of certain fresh invertebrate tissues. P. S. Galtsoff (*Stain Technol.,* 31, 231–233, 1956) described a method for making frozen sections of oysters and clams with a standard rotary microtome and a "cold" blade. Galtsoff's method for glycogen tests proved to be unsatisfactory for shellfish pathology. To meet our needs a method for making entire, uniform sections of shellfish in a microtome-cryostat[1] was developed and is described here.

A uniform, transverse segment, no thicker than 2 mm, is cut from the visceral mass of shellfish with a sharpened single-edge razor blade. Tissues are frozen to the object holder with a drop of tap water in the quick-freeze unit of the cryostat. Very small or thin slices can be "mounted" on a drop of water that has partially frozen. Better sections are obtained if the tissues are oriented so that the blade cuts into the posterior edge of the oyster. Proper orientation is easily accomplished if each object holder is marked to show the position of the set-screw hole by making a slight groove in the top of the disc with a metal file. Slender triangular identification labels, cut from file cards, are placed on the object holders before the water and tissues are added.

Sectioning (routinely at 6 μ) is begun as soon as the tissues are frozen. The section is picked up on a cover glass held at room temperature, dipped immediately into undiluted Paragon[2] stain, then quickly rinsed in a beaker of clean tap water. The washing is continued until no stain runs off. Excess water is blotted from the edge of the cover glass and the section is mounted in glycerin.

Although most of our frozen sections are preparations of the visceral mass of several species of oysters, good sections have also been obtained from the pericardial region of oysters and from gonadal tissues of the soft-shell clam, *Mya arenaria.* Serial sections of oyster tissues can be made rapidly with this quick-staining technique. Unwrinkled, uniform sections as thin as 2 μ have been made.

Mounted stained sections can be kept for an indefinite period in a refrigerator freezer without deterioration; however, Paragon stain fades at room temperature when the mount is in glycerin. Paragon mounting medium, a semipermanent mountant, has been used but it destains the Paragon stain quickly. Several permanent stain techniques, including hematoxylin-eosin, modified specifically for frozen sections, have been tried but have proven unsatisfactory for oyster tissues. The cells, though in good condition when first stained, became distorted as the mounting medium dried. Toluidine blue O, in a 0.5% aqueous solution, has also been used; although it is satisfactory, the Paragon stain gives clearer differentiation of cells and microorganisms.

In a search for the freezing method giving the best sections, oyster tissues were frozen in an acetone-Dry Ice bath at a temperature of −70°C. The tissues froze within 10 sec, but did not section well. When these tissues were wrapped in plastic film or placed in a tightly closed jar overnight in the chamber of the cryostat, excellent sections could be made but this delay defeats the advantage of frozen sectioning. Tissues can be frozen by CO_2 gas or Dry Ice, but the cryostat contains a Freon unit which quick-freezes tissues in 1 to 2 min—rapid enough to avoid dehydration and formation of ice crystals. An essential accessory is the preset plane device to grip the object holders and permit setting the angle of the object holder to the blade; this device eliminates the time-consuming adjustment with each specimen.

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[1] International-Harris cryostat, Model CT, manufactured by International Equipment Co., Boston, Massachusetts. (Mention of commercial products does not imply endorsement by the Bureau of Commercial Fisheries).

[2] Paragon Multiple Stain, Paragon C. & C. Co., Inc., 190 Willow Ave., Bronx, New York 10454.

Application of the frozen-section technique to shellfish tissues makes possible microscopic examination for infective agents within 10 min from the time the specimen is brought in from its natural environment. Thus the immediate pursuit of research projects that employ fresh tissues is feasible, and chemical or biological changes which may occur with storage are avoided.

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Received March 30, 1967

Reprinted from Proceedings, Washington State University's
Sixth Biennial Hydraulics Conference, Moscow, Idaho, 1967

RESEARCH ON FINGERLING MORTALITY IN KAPLAN TURBINES

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INTRODUCTION

Most of you are familiar with the problem posed by dams to runs of anadromous fish, especially on the Columbia-Snake watershed where low-head dams are numerous. Several problems must be solved if we are to enjoy the benefits of hydroelectric power and anadromous fish simultaneously. Although significant progress has been achieved in passing adult salmonids over dams, little has been done to protect the fingerlings migrating seaward. The Bureau of Commercial Fisheries has a program of research on this problem which is the subject of my discussion today.

The fish-versus-dam problem is not confined to the Columbia and Snake Rivers; our solutions can be applied on many rivers with similar problems. The most important application may be in Alaska (Figure 1) or in British Columbia, where important fish runs are shared by Canadian and American fishermen.

The passage of fingerlings at low-head dams on the Columbia-Snake watershed is a problem of attrition. When all of the low-head dams are completed, the progeny of some of our most important stocks of fish will be forced to pass through either the spillways or the turbines of about 10 low-head dams to reach the sea (Figure 2). The fish that use the spillways enjoy relatively safe passage. When the storage reservoirs are completed, however, nearly all of the water will pass through the turbines, where losses of fish are now estimated at 11% (1). Such losses at each of 10 dams would seriously deplete the runs and would make perpetuation of important fish stocks impractical.

The Bureau's research is directed toward reducing this type of loss. Although laboratory research plays a vital role in the Bureau's plans, we recognize that final evaluation of fish-protection measures must be made in the field. At the outset, we realize that practical solutions required greater knowledge of fish behavior near dams; the distribution of fish in time and space, for example, would bear directly on where and how extensively protection measures would have to be deployed, and when and for how long each year they would have to be in operation.

Our preliminary objective, therefore, was to develop and perfect our capability for conducting research in full-scale turbines. In my discussion today, I will describe our present concept of the problem (gained primarily through field research), our general approach, and some potential solutions which will be tested shortly in the field.

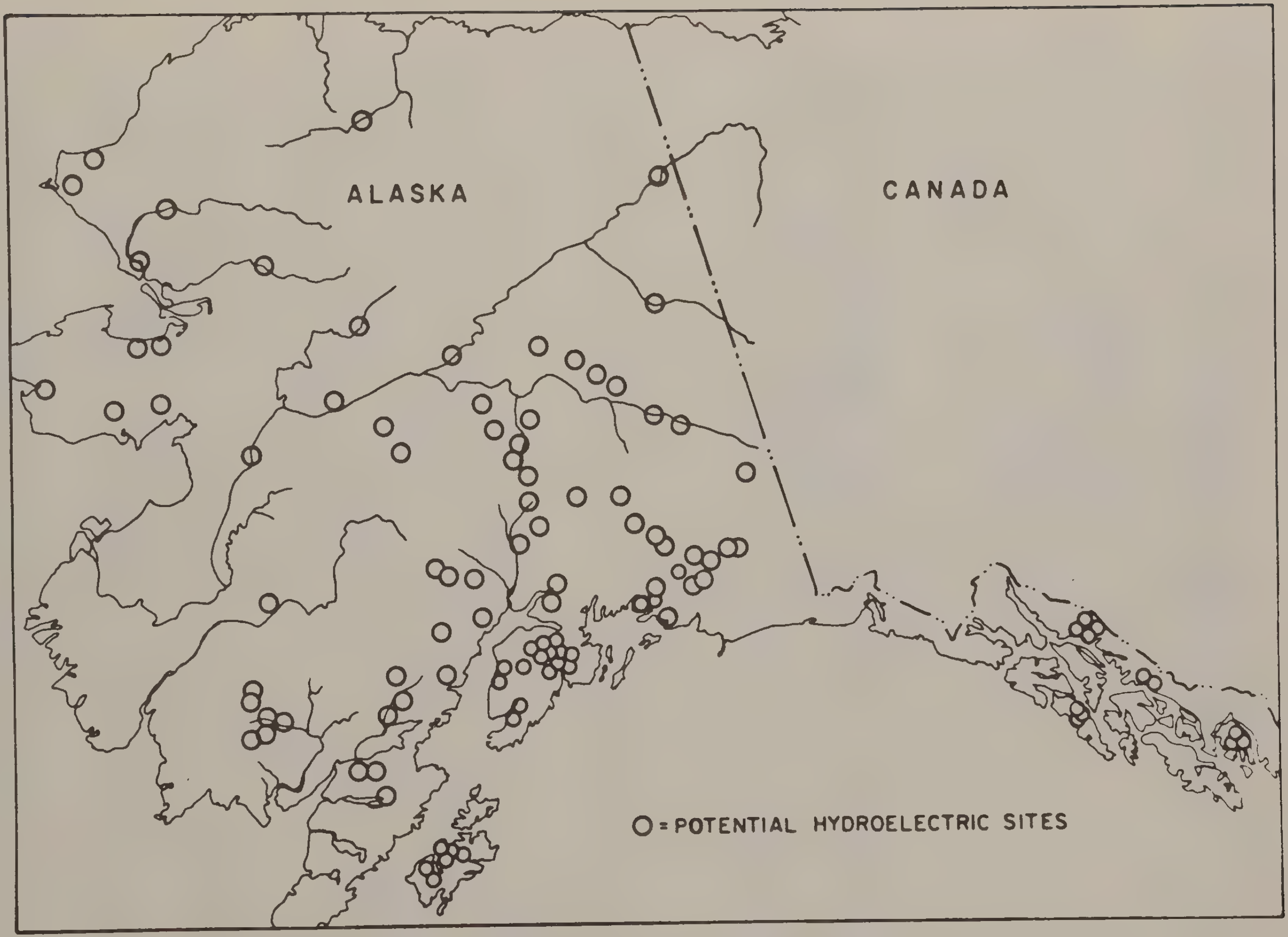

ALASKA
CANADA
O = POTENTIAL HYDROELECTRIC SITES

Figure 1. Locations of 98 potential hydroelectric dam sites under investigation by U.S. Army Corps of Engineers in Alaska.

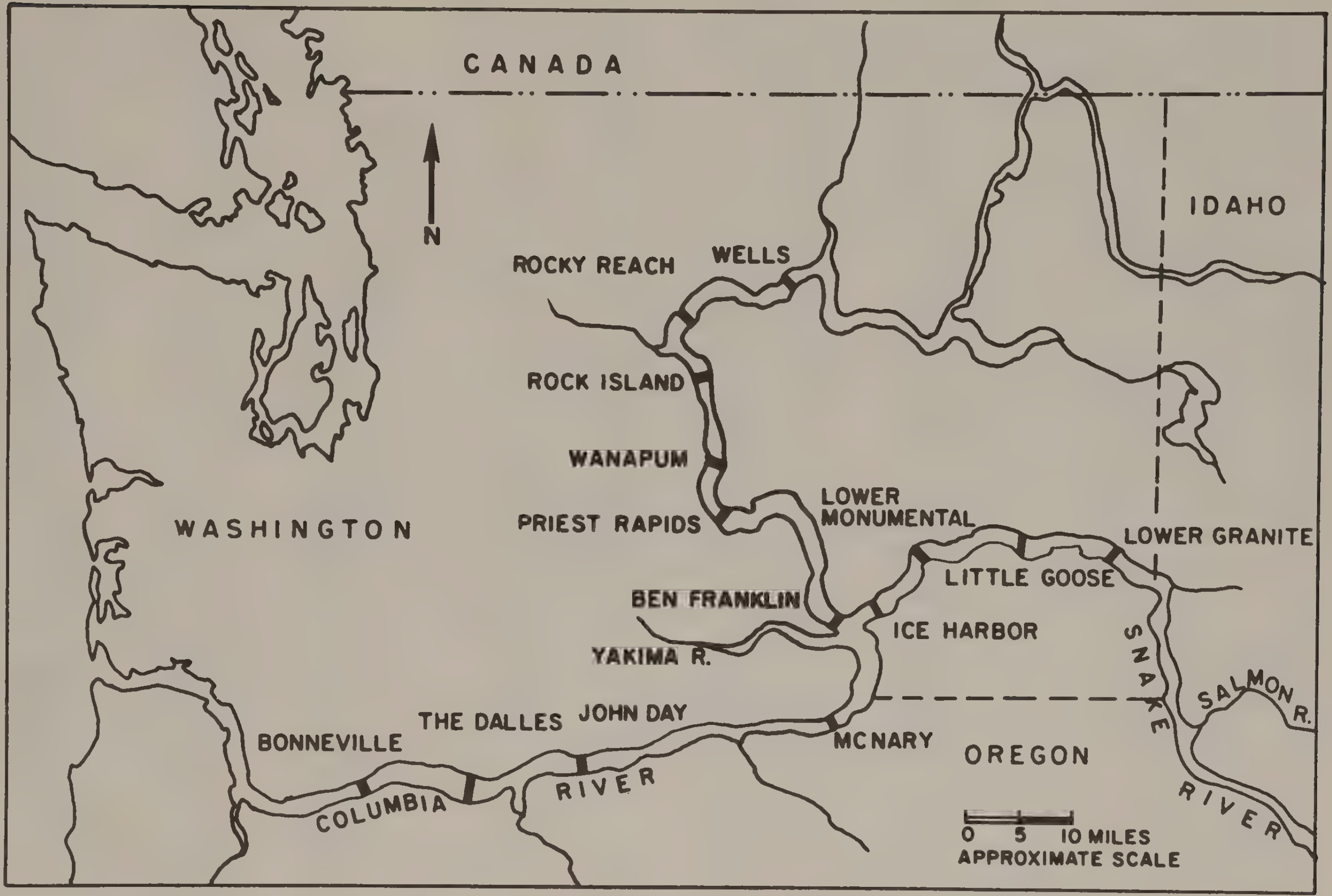

CANADA
IDAHO
N
ROCKY REACH
WELLS
ROCK ISLAND
WANAPUM
PRIEST RAPIDS
WASHINGTON
LOWER MONUMENTAL
LOWER GRANITE
LITTLE GOOSE
BEN FRANKLIN
ICE HARBOR
YAKIMA R.
SNAKE RIVER
SALMON R.
JOHN DAY
THE DALLES
BONNEVILLE
MCNARY
OREGON
COLUMBIA RIVER
0 5 10 MILES
APPROXIMATE SCALE

Figure 2. Locations of present and future low-head dams on the main stems of the Columbia and Snake Rivers.

GENERAL METHODS FOR PROTECTING FISH

The direction of our program is determined somewhat by the nature of the solutions that will ultimately be applied to safeguard fingerling salmonids. Fish-protection methods fall into three general categories: (a) operating turbines to minimize mortality, (b) eliminating lethal agents within turbines, and (c) bypassing fish around turbines. At present we assume the ultimate solution may be to combine several methods within one or more of the three general categories. Our research is designed to answer specific questions related to each method of protecting fish. The following discussion will serve to demonstrate how the nature of the methods has influenced the direction of our research.

Operating Turbines

Research showing that survival is highest at loads producing maximum turbine efficiency points to the possibility of deliberately controlling turbine loads to minimize mortality. The most recent work in this area was at Big Cliff Dam (2).

The degree to which fish survival can be increased depends upon several factors. The maximum potential increase in survival is obviously the difference between that mortality normally experienced and the minimum mortality that would occur if all turbines were operated at maximum efficiency at all times. Flexibility in controlling turbine loads to aid survival varies each day, season, and year because of the fluctuating needs of other water users.

In the final analysis, the hour and season of passage through turbines dictates when turbine loads should be controlled; the distribution of fish along each powerhouse and within the Columbia-Snake system at any moment also dictates which turbines should be controlled. To estimate the potential increase in survival resulting from the control of turbine loads will require research in the field. Determinations will have to be made of the mortality, the time of migration, and the distribution of fish in the vicinity of dams.

Eliminating Lethal Agents

The causes of death and injury to fingerling salmonids are largely a matter of speculation at this time. Factors that are suspect include cavitation, low pressures, shear planes of water associated with zones of turbulence, and of course, contact by the fish with solid objects. All of the suspected lethal agents are associated with structures lying in the path of the water.

Kaplan turbines are large; extensive modifications of structures would be expensive. Hopefully, a minimum number of structures would be involved. Perhaps only a small portion of each structure requires modification. Knowledge of the distribution of fish within the water mass is desirable to determine the magnitude of the problem.

As an experimental approach, fish could be released in specific zones within turbines to determine mortality associated with various structures. In this way we might identify "dangerous" and possibly "safe" zones. When this information is studied in relation to the natural distribution of fish, we can determine where and how extensively modifications must be applied. Methods for releasing fish at several specific locations immediately upstream of turbines are necessary.

Laboratory research may provide much needed information that cannot be obtained in full-scale turbines; it could even provide the key for making turbines safe. Modifications that may increase survival, however, must be evaluated in prototypes. The ultimate solution may combine several low-cost modifications, each providing a small increase in survival. Because normal mortality is about 11%, several solutions cannot each provide a large benefit. Not only must we develop the capability to measure fish mortality in full-scale turbines, but our techniques must be sensitive enough to detect minute increases in survival or we may fail to identify valid solutions.

Bypassing Fish

Bypassing fish around turbines was one of the first approaches considered by investigators concerned with developing fish-protection methods. The problem appears formidable indeed when one views the debris-laden vastness of the Columbia and Snake Rivers during the spring. When one considers the number of dams involved, it is not easy to imagine economically feasible, let alone practical, guiding devices.

The attack on this problem has been twofold: (a) Field studies in the vicinity of dams have focused on distribution of fish. Usually fish are not randomly distributed throughout the water mass, but are concentrated. Knowing when and to what degree fish are concentrated will allow us to reduce the size and cost of guiding devices. (b) Development of new guiding devices is continuing. The major objective has been improved efficiency at lower cost.

The prospect of duplicating at each dam what may at best be a very expensive bypass system, however, continues to be of great concern. This concern has led to the concept of employing guiding systems at a few key dams in the upper reaches of the system and then transporting the collected fish (by barge or other means) around the remaining dams.

The success of this plan depends in part on the ability of the transported fish to find their way back as adults to their spawning grounds. Plans are currently underway to determine if fish can be transported great distances as fingerlings without affecting their homing ability.

KAPLAN TURBINES AND ASSOCIATED WATER PASSAGES

In this section I would like to review briefly the design and operation of a typical main unit (turbine and associated structures) to call to your attention how certain design characteristics have influenced the direction of our research on the fish-mortality problem.

Main units (Figure 3) can be described as consisting of three intakes, a water distributor (spiral or scroll case), structural supports called stay vanes, wicket gates for water control, a Kaplan runner, and two draft tubes.

Turbine intakes are equipped with trash racks that completely span the mouth of the intakes. These trash racks are built of steel bars, oriented vertically and edgewise to the water flow, and spaced 6 inches apart. The trash racks, designed to withstand forces equal to a complete block of the water, are capable of supporting structures designed to guide fish.

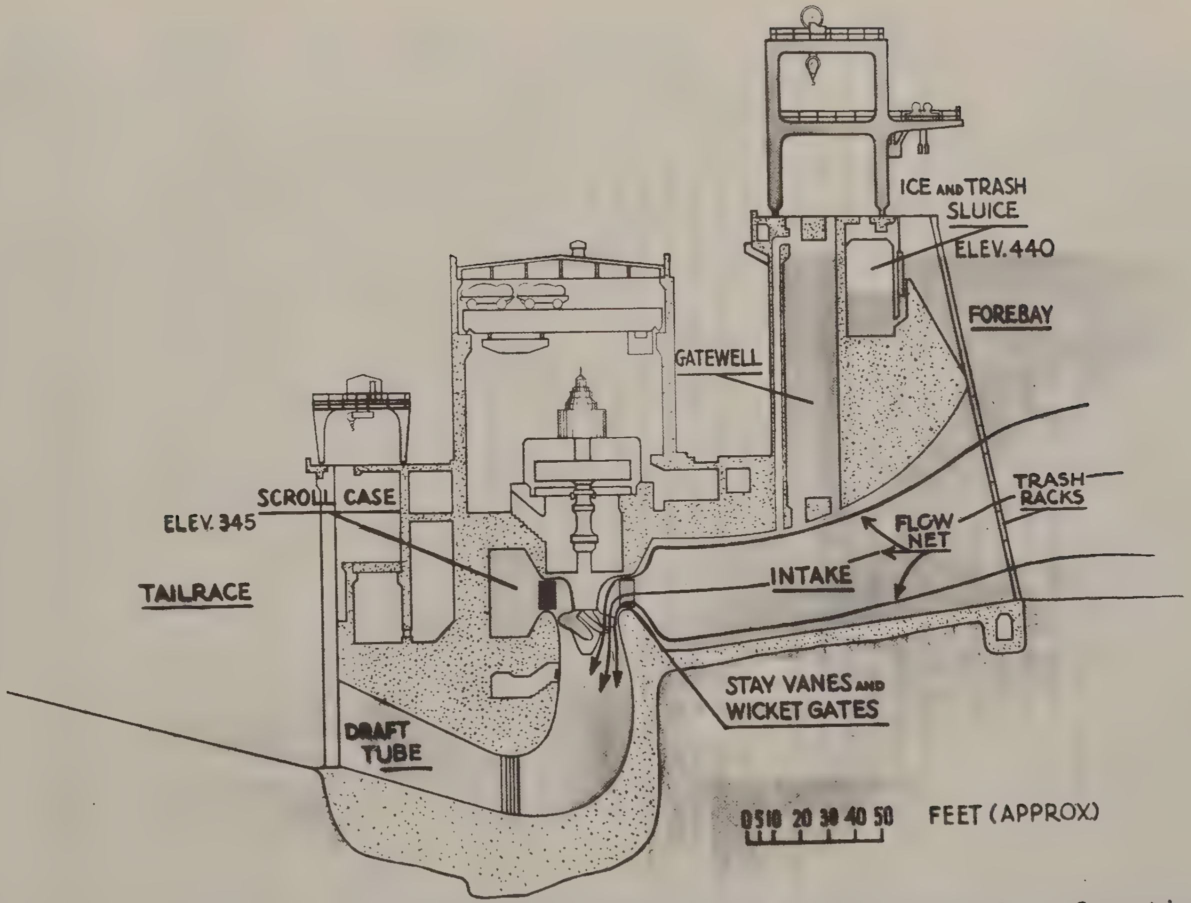

ICE AND TRASH SLUICE
ELEV. 440
FOREBAY
GATEWELL
TRASH RACKS
FLOW NET
INTAKE
STAY VANES AND WICKET GATES
SCROLL CASE
ELEV. 345
TAILRACE
DRAFT TUBE
0 5 10 20 30 40 50
FEET (APPROX)

Figure 3. Section through typical main Kaplan unit showing general conformation and major features. Flow paths in intake and scroll case are generally consistent and predictable.

All turbine intakes are equipped with gatewells, although their designs and dimensions vary considerably among dams. Gatewells are normally designed as cul-de-sacs. These areas are important to biologists because significant numbers of fish enter them before eventually passing on through the turbines. In addition, the gatewells provide a means for installing research equipment in turbine intakes.

Many of the earlier dams are equipped with ice and trash sluiceways adjacent to the gatewells. The sluiceways represent potential bypasses for transporting fingerling salmonids either from the forebay or from intake gatewells to the tailrace. Dams now under construction will not be equipped with sluiceways; however, the Corps of Engineers has designed into all future dams special bypasses intended for eventual use in transporting fingerlings from gatewells to the tailrace.

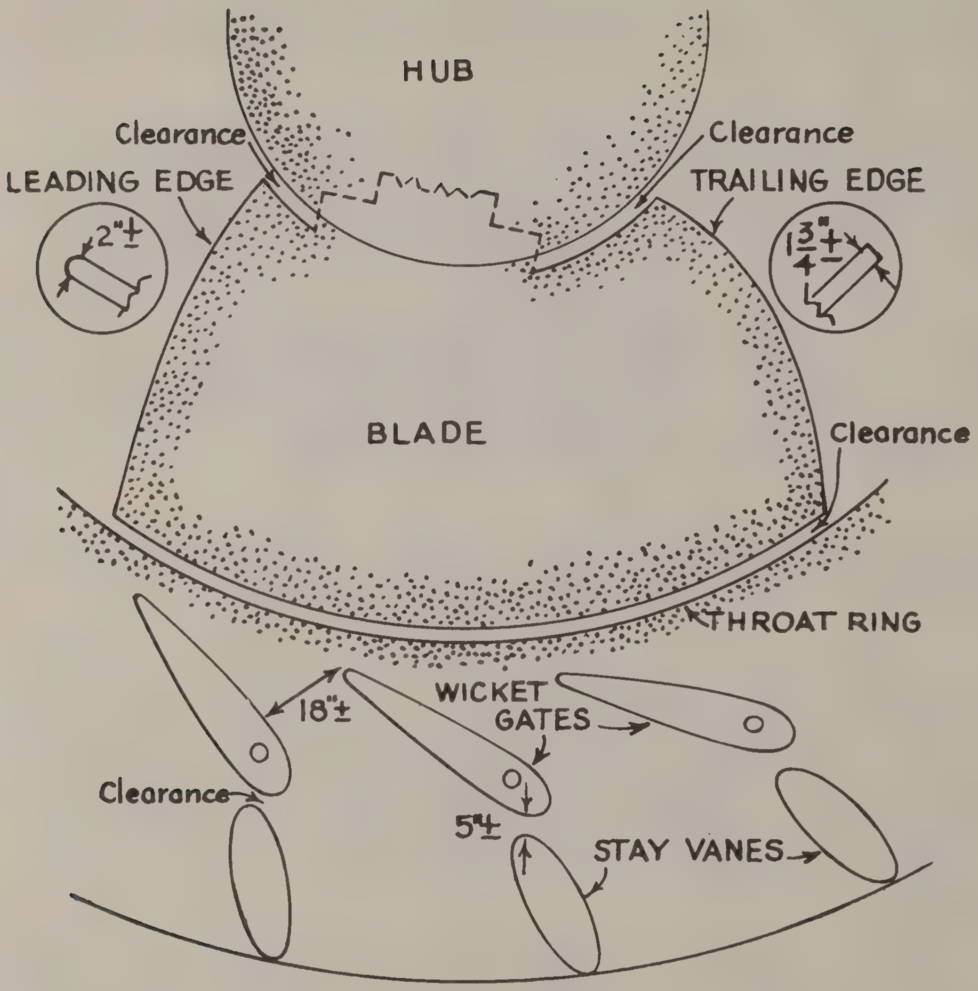
The flow patterns within turbine intakes and scroll cases can be called well-ordered. Model studies show that flows near intake ceilings pass through the tops of the openings between wicket gates and that flows near intake floors pass through the bottoms of these openings (Figure 3). Because the runner is only a few more feet downstream, we can predict with some confidence that ceiling and floor flows probably maintain the same relationship as they pass the blades.

This information becomes more meaningful when we consider that the vertical distribution of fish in the intake flows probably controls the distribution of fish across the runner. If one is known the other is predictable, provided that fish distribution in the flows does not change.

The final point I wish to make concerns how and where fish might be killed as they pass through a Kaplan turbine. As a fish approaches a turbine, the first structures it encounters are the stay vanes and wicket gates (Figure 4). At certain high loads, a zone of minimal clearance is formed between the trailing edge of each stay vane and the leading edge of the corresponding wicket gate that may cause mortality. Clearance at this zone (at Ice Harbor Dam) measure about 5 inches across and are equal to about 28% of the total open area between wicket gates. Presumably, significant numbers of fish pass through these narrow zones. Turbine loads found to produce lethal conditions at the wicket gates probably could be avoided without too much difficulty.

The next structures of importance are the variable-pitch turbine blades. At the hub, the base of a blade on either side of the blade shaft is constructed to conform roughly to the shape of the hub (Figure 4). A zone of minimal clearance is needed between the blade and the hub to make it possible to change the pitch of the blade. The dimensions of this zone are not critical to turbine efficiency, but may be of importance to the fish. Certainly, the dimensions of this clearance could be reduced if this reduction would increase survival. Turbine efficiency even may increase slightly. A zone of minimal clearance also is formed between the blade tips (periphery of the runner) and the throat ring (Figure 4). It appears that little can be done to modify this zone even if it is significant in killing fish.

That portion of the blade between the base and the tip is divided into three parts, each of which may produce lethal effects. The first part is the leading edge of the blade, the second is the boundary zone along the underside of the blade, and the third is the trailing edge.


HUB
Clearance
LEADING EDGE
2" ±
Clearance
TRAILING EDGE
1 3/4" ±
BLADE
Clearance
THROAT RING
18" ±
WICKET GATES
Clearance
5" ±
STAY VANES

PLAN VIEW
NOT TO SCALE

Figure 4. Schematic drawing of zones of minimal clearance in Kaplan turbine plus typical dimensions and shape of leading and trailing edge of blades.

Calculations analagous to those made by von Raben (3) indicate that at Ice Harbor Dam, about 22 to 30% of the fish (6-inch fingerlings oriented at random with the flow path) pass within 3 inches of a blade when the turbine is operating at maximum rated output.

The leading edge of typical Kaplan blades has a thickness of about 2 inches and a radius of curvature of about 1 inch (Figure 4). The speed of the blade varies from 45 feet per second (fps) at the hub to 110 fps at the tips.

Presumably, blade velocity, thickness, and shape combine to determine whether a fish of a given size will be struck or merely shunted aside by the static buffer zone of water in front of the leading edge. If this site were found to cause significant mortality, would it be possible to modify the shape or thickness to increase the depth of the static zone and decrease, in turn, the number of fish struck by the leading edge of the blade?

The boundary layer beneath and adjacent to each blade is believed to be an area of very low pressure (in comparison with average pressures throughout the water mass). In addition, this zone may be the site of some turbulence, especially near the trailing edge of the blade.

The third part of the blade, the trailing edge, is a site characterized by low pressures and cavitation, turbulence, and shear planes. It may be possible to modify the trailing edge (Figure 4) to alleviate the effects of shear planes.

The terminal end of the hub is believed to be the site of a large, steady state zone of low pressure that may cause mortality. In some turbines the hub is stubbed off at the terminal point (Ice Harbor Dam), whereas in others the hub gradually tapers to a small point (The Dalles Dam). The effects of different hub designs on the production of the steady-state zone of low pressure are not known. Apparently, variations in design are not critical to turbine efficiency and the hub could be modified to some extent if desirable.

These are the structures and associated phenomena that may be causes of fish mortality in turbines. Field and laboratory experiments are designed accordingly.

EQUIPMENT AND TECHNIQUES FOR FIELD RESEARCH

To date a large portion of our total effort has been expended in developing the capability for conducting research in full-scale turbines. Equipment has been developed for (a) studying the behavior of fish in the vicinity of dams, (b) measuring fish mortality in Kaplan turbines, and (c) indexing the production of cavitation within turbines.

Sampling Fish in Turbine Intakes and Gatewells

The distribution and time of passage of fingerling salmonids at dams have been measured with a special frame designed to place fyke nets within turbine intakes, and with a simple dip net designed to remove fish from intake gatewells.

Intake frames are constructed of pipe or angle iron to fit the bulkhead gate slots (extending through the gatewell to the bottom of the turbine intake). In general, these frames are 45 to 52 feet high, 22 feet wide, and 2 to 3 feet thick, and may weigh 10,000 pounds or more (Figure 5). Fyke nets are placed in the frame to strain the entire flow or a portion of the flow passing through the intakes.

In operation, the frame is lowered through the gatewell by means of a crane or with hoists temporarily installed on the forebay deck. The turbine is shut down during installation and removal of the frame to prevent capture of fish while the nets are moving up or down. The design and operation of intake frames were discussed in detail by Long (4).

Fish are removed from intake gatewell with a simple dip net constructed to fit the rectangular shape of the gatewells. In operation, a dip net is lowered to the bottom of the gatewell in a folded position, opened, and raised to strain nearly all of the water in the gatewell (Figure 5). Bentley and Raymond (5) discussed the use of gatewell dip nets in greater detail.

Measuring Mortality in Turbines

For mortality studies, equipment has been designed for holding and transferring fish, releasing fish at any location upstream and downstream of turbines, and recovering fish below turbines. Marquette et al. (6) explained in detail the design, operation, and evaluation of this field equipment.

Holding and transferring fish.--Possible trauma associated with handling fish during experiments is minimized by using equipment that does not require removal of the fish from the water (except for marking). A siphon is used to divide a group of fish randomly into several subgroups (Figure 6). The subgroups are then held in pens of perforated aluminum, the bottoms of which are nonperforated fiberglass funnels which retain small amounts of water together with the fish when the pens are raised out of a pond for transfer (Figure 6). Fish in some experiments have been moved and transferred up to 14 times without being taken from the water except to be marked.

Releasing fish.--Fish can be released at almost any location within turbine intakes and at draft tube exits either with hoses or with fish-release capsules (Figure 7). With a hose, large numbers of test fish may be released over a long or short period of time. Where fish are to be released at several locations simultaneously, however, manpower requirements are high, because each hose requires at least one operator.

One operator can release fish by remote control from several fish-release capsules deployed in different locations. The capsules are aluminum tubes 6 inches in diameter and 5 feet long; they have a screen at the front and a solid door at the rear that is opened to release the fish by a two-way, air-driven piston. A single capsule carries 50 to 150 fish, depending on their size.

The depth of the hose exit and capsules is controlled by a combination of weight and air-buoyancy chambers. Lead shot, used for weight, insures against damaging the turbine in the event the weight should break loose. Air is pumped into the chambers by remote control to adjust the depth.

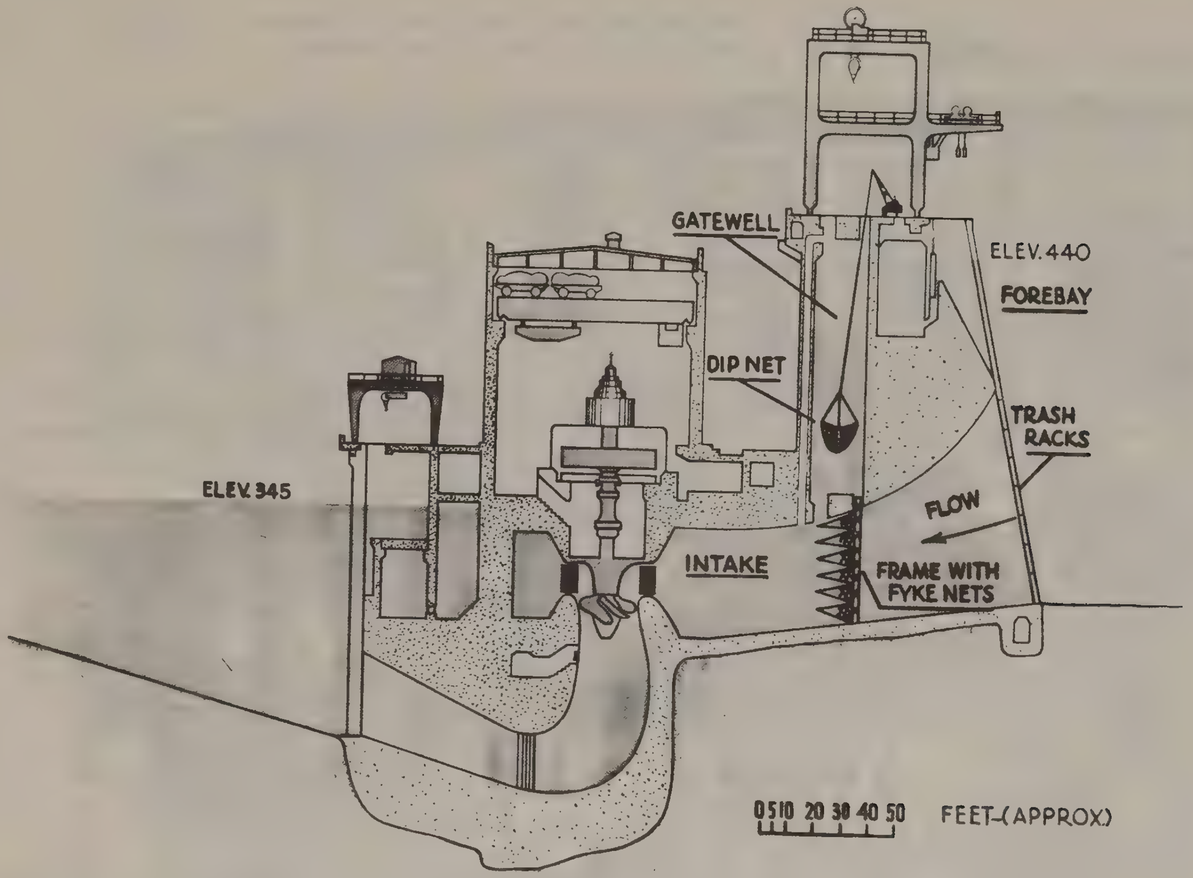

GATEWELL
ELEV. 440
FOREBAY
DIP NET
TRASH RACKS
ELEV. 345
FLOW
INTAKE
FRAME WITH FYKE NETS
0 5 10 20 30 40 50 FEET-(APPROX.)

Figure 5. Intake frame (with fyke nets) used to measure vertical distribution and time of passage of fingerlings; dip net used to remove fingerlings from gatewell.

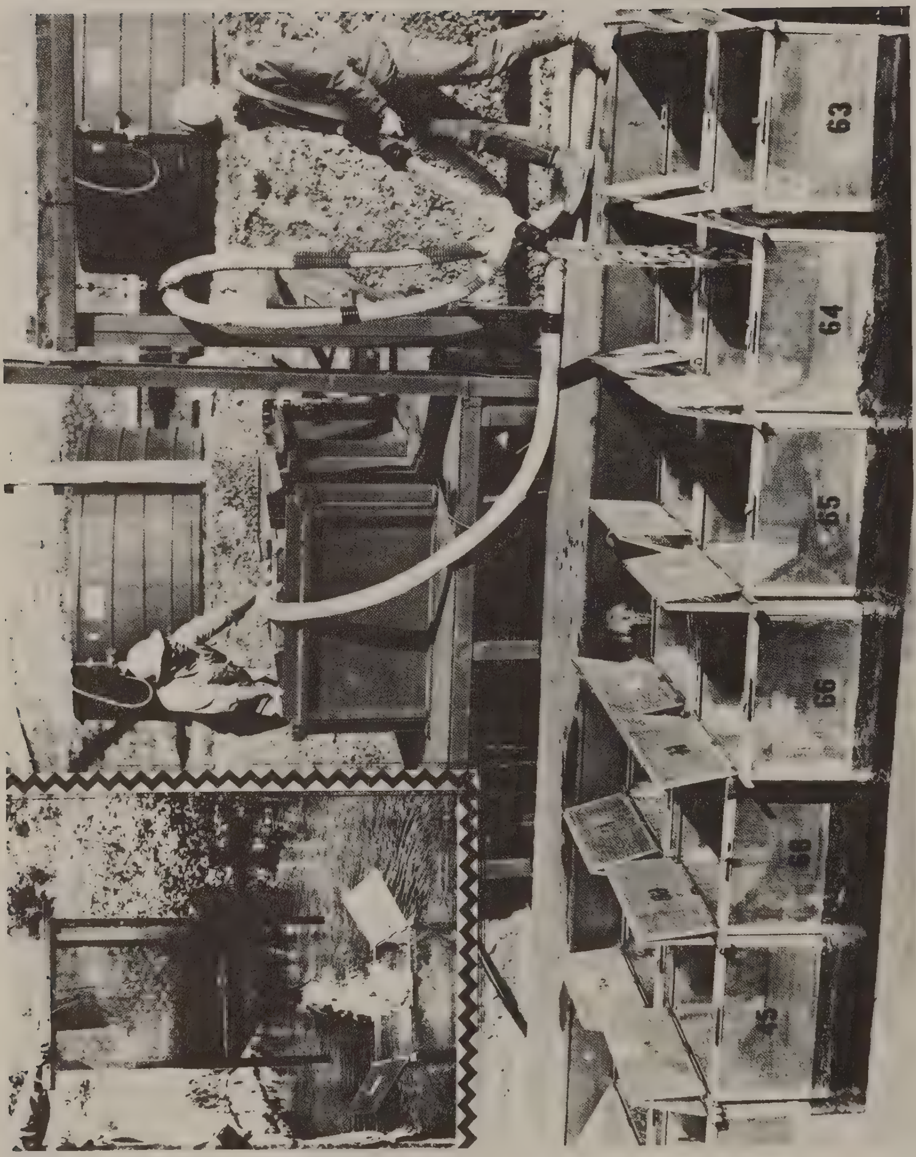

63
64
65
66
68
45

Figure 6. A siphon and holding pens (insert) allow fish to be transferred without removing the fish from the water.

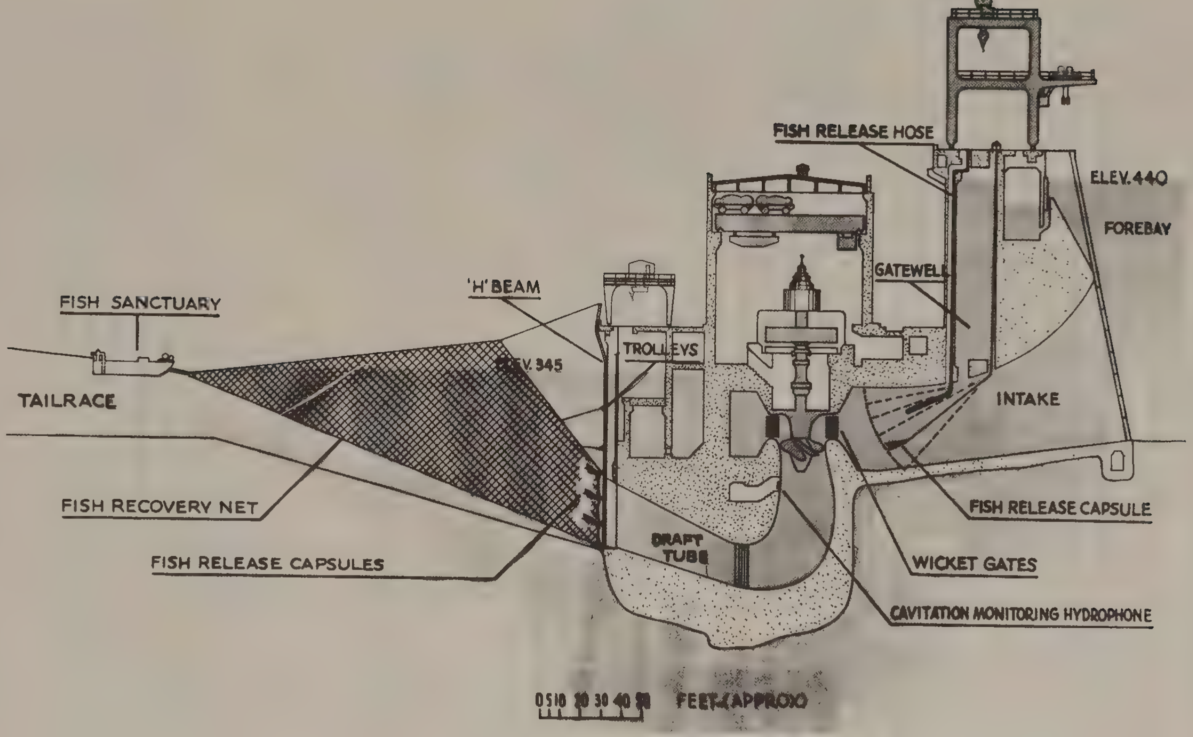

FISH RELEASE HOSE
ELEV. 440
FOREBAY
GATEWELL
INTAKE
'H' BEAM
FISH SANCTUARY
TROLLEYS
ELEV. 345
TAILRACE
FISH RECOVERY NET
FISH RELEASE CAPSULE
FISH RELEASE CAPSULES
DRAFT TUBE
WICKET GATES
CAVITATION MONITORING HYDROPHONE
0 5 10 20 30 40 50 FEET-(APPROX)

Figure 7. Section through typical main unit showing location of equipment for releasing fish, recovering fish, and indexing the production of cavitation.

Recovering fish.--Two methods of recovering fish below turbines have been developed. One method employs a large funnel net affixed to the draft tube exits to strain the entire discharge of a single turbine (Figure 7). For the second method, a percentage of the survivors of test and control fish is recovered from the intake gatewells of the next dam downstream.

Advantages of the funnel net method are: (a) A large percentage of the fish passed through the turbine can be recovered immediately to allow rapid testing; (b) dead and injured (as well as live) fish can be recovered to provide information on cause of death; and (c) tests can be conducted at any time of the year.

The funnel net developed at Ice Harbor Dam is 175 feet long and has a mouth 82 feet wide and 32 feet high. A fish-sanctuary barge sucks fish out of the downstream end of the net to protect the fish from impingement against the webbing. Fish entering the barge are separated automatically from most of the flow and shunted into sanctuary traps.

The funnel net used at Ice Harbor Dam has not been satisfactory for measuring fish mortality in turbines. Calibration tests show that fish entering the net may suffer from 0 to 11% (or more) mortality within the net, depending upon the part of the net entered. A high and variable mortality by the recovery gear makes assessment of turbine mortality difficult.

Advantages of the "gatewell" method are based on the hypothesis that fish are killed indirectly by the turbine as well as directly. Although some fish are killed by mutilation, decompression, or other effects within turbines, others may be stunned temporarily and made more susceptible to predation (7). If indirect mortality represents a large segment of the total mortality caused by turbines, a true measure might best be obtained by allowing direct and indirect mortality to occur naturally. This is accomplished by sampling the survivors of test and control fish at a point several miles downstream, such as with gatewells.

Recovering fish from intake gatewells to obtain estimates of mortality in turbines is a relatively new technique and has not been fully evaluated. Preliminary studies indicate that very large numbers of fish are required to detect small differences in mortality.

In spite of the effort expended in the development of methods for measuring mortality in turbines, we have not yet attained the required precision. Increased emphasis on this problem is necessary.

Indexing Production of Cavitation Within Turbines

Laboratory research by Muir (8) showed that cavitation could kill fingerlings. One of the objectives of the Bureau's research is to determine if cavitation causes mortality of fish in prototype turbines. A desirable approach was to compare fluctuations in mortality with fluctuations in cavitation as conditions within turbines were changed; however, a suitable method for estimating the amount of cavitation was not available.

Others have measured the noise produced by cavitation to study the phenomenon in the laboratory. Because this approach provided a direct measure of the phenomenon, we decided to adapt the method for use in full-scale turbines. Jensen and Long (9) described the advantages and limitations of the method. Briefly, a hydrophone is locked through the steel liner of the draft tube into the flow at a point about 15 feet below the blade (Figure 7). The noise picked up by the hydrophone is recorded on strip charts or registered on an oscilloscope where it can be seen or photographed. Although the system cannot discern the location of the cavitation, changes in its production are readily determined.

FISH BEHAVIOR IN THE VICINITY OF DAMS

Research on the behavior of wild fingerlings in the field has been concentrated on determining the time when fish are in the vicinity of dams and their distribution.

Time of Migration

Fingerling salmonids generally migrate during April and May; 80% of the migration to sea is at this time at McNary Dam[1]. At some dams, consistent off-season outmigrations tend to complicate matters; e.g., significant numbers of fingerlings pass through Priest Rapids Dam during July and August, but few are detected at McNary Dam, indicating the migration is incomplete[2].

Day-night (diel) passage of fingerlings through turbines has been measured only once. Long (4) found 85 and 95% of the I-group (1 year old or older) steelhead trout (Salmo gairdneri) and chinook salmon (Oncorhynchus tshawytscha), respectively, passed through the turbines at The Dalles Dam between 7 p.m. and 7 a.m. (Figure 8). About 65% of the O-group (underyearling) fish were also caught during this time period. The portion of the run occurring at dawn and dusk was not measured. Research in river sections indicated that peak movements of fish are at dawn and dusk (10, 11, and 12).

Diel movement of fish and normal fluctuations in power demand appear basically compatible. At night, when most fingerlings pass through turbines, power demand is normally reduced, thus increasing flexibility for adjusting turbine loads. Present information must be qualified, however, because of the lack of data on movement of fish at dawn and dusk. At these times, power demand is sharply increased. The percentage of fish that pass through turbines at these critical time periods could seriously influence the feasibility of this protection method.

Distribution

The distribution of fingerlings at dams has been studied to determine where fish are most concentrated. Fingerlings entering turbine intakes are not randomly distributed from top to bottom but are concentrated near intake ceilings. At The Dalles Dam and McNary Dam, Long (4) found 70% of the I-group fingerlings within 15 feet of the intake ceilings (Figure 9).

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[1] Howard L. Raymond, Bureau of Commercial Fisheries, Biological Laboratory, 2725 Montlake Boulevard East, Seattle, Washington, 98102. Personal Communication.

[2] Donn L. Park, Bureau of Commercial Fisheries, Biological Laboratory, 2725 Montlake Boulevard East, Seattle, Washington, 98102. Personal Communication.

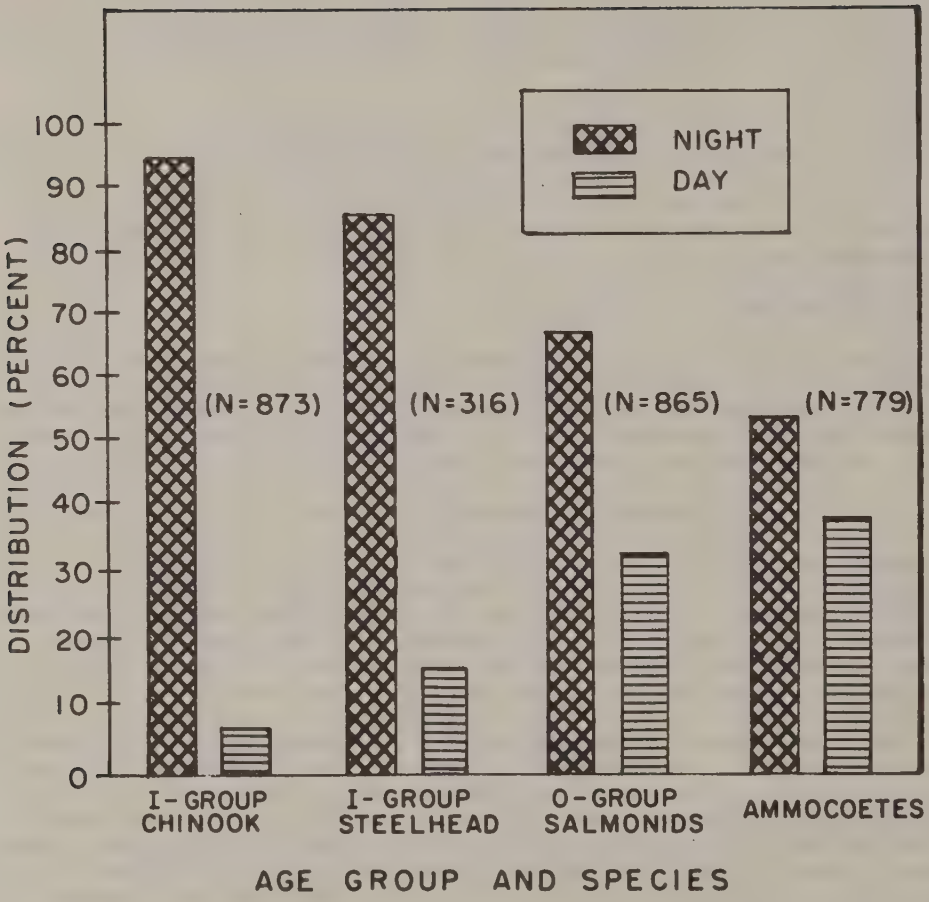

Figure 8. Comparison of day (7 am to 7 pm) and night (7 pm to 7 am) catches of juvenile anadromous fish in turbine intakes of The Dalles Dam during 18 tests, April 7 to 27, 1960.

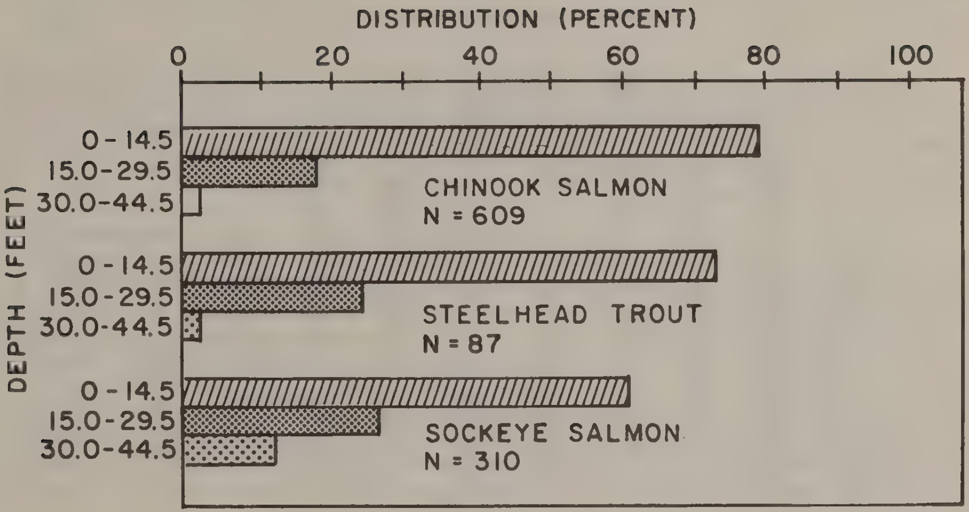

Figure 9. Vertical distribution of I-group salmonids in a turbine intake (immediately below the gatewell) at McNary Dam, April 24 to May 26, 1961. Results were similar at The Dalles Dam.

The vertical distribution of the fish in turbine intakes probably determines the distribution of the fish across the runner. Our knowledge of the flow regime upstream of turbines (Figure 3) indicates that flows near intake ceilings probably pass the runner at or near the hub. Because most fish are found in these flows, we assume the fish also pass the runner at the hub. Therefore, methods for eliminating lethal agents should be applied first at the hub.

The concentration of fish near intake ceilings no doubt is responsible for the entrance of significant numbers of fish into gatewells. Raymond (see footnote 1) reported that over 850,000 fingerling salmonids were removed from the gatewells of five low-head dams in 1967 during studies on the rate of movement and seasonal timing of fingerling outmigrations.

The gatewell catches across powerhouses also provide information on the horizontal distribution of fish entering the turbines. Park (see footnote 2) reported that about 82% of the O-group chinook salmon fingerlings were removed from 70% of the turbines at Priest Rapids Dam in July and August 1965 (Figure 10). Preliminary evidence indicates that similar concentrations may occur at The Dalles Dam. It may be possible to reduce costs of fish-protection methods up to 20% at some dams without significantly affecting total survival. This type of information also dictates which turbines should be controlled first to achieve maximum survival. It is possible, of course, that benefits obtained from reducing turbine loads may be negated by changes in horizontal distribution of fish across the powerhouse due to the reduced turbine discharges.

The accident in design that causes significant numbers of fish to enter intake gatewells offers exciting possibilities for bypassing fish. At present, we visualize gatewells as the port of entry of a bypass system. It seems reasonable to suppose that we can devise methods for diverting fish into the gatewells, particularly the concentrations that pass within a few feet of the gatewell entrances.

FUTURE RESEARCH

Measuring Mortality in Prototype Turbines

Our capability for measuring the mortality of fish in full-scale turbines is insufficient. Research in the immediate future must concentrate on this problem, for evaluation of different protection methods will otherwise be delayed.

Operating Turbines to Protect Fish

Although research at Big Cliff Dam (2) indicated that survival is highest at peak turbine efficiency, the potential increase in survival in the larger Kaplan turbines on the Columbia and Snake Rivers has not been determined. Until survival in these larger turbines is established, potential benefits to be derived by controlling turbine loads cannot be estimated. Action on this aspect will no doubt be held in abeyance pending definite measures of turbine mortality.

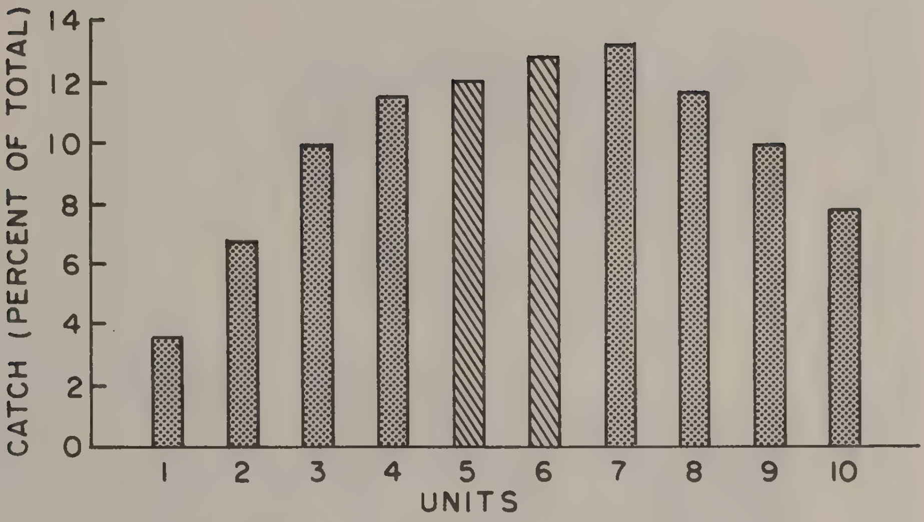

Figure 10. Gatewell catches at Priest Rapids Dam indicate 82% of 38,086 O-Group chinook salmon fingerlings passed through 70% of the turbines. Data obtained July 6 to September 9, 1965. Turbines 5 and 6 were not available for sampling in 1965. Proportions of fish entering gatewells of these turbines were calculated from 1966 data when complete sampling was possible.

Eliminating Lethal Agents Within Turbines

Neither laboratory nor field research has provided information on the relative importance of the various causes of fish mortality in Kaplan turbines. It has been shown (13) that the basic design of Francis turbines can influence the general level of mortality, and presumably this holds true for Kaplan turbines. The standard engineering parameters involved are sigma, specific speed, and turbine efficiency (14). Further research is necessary to determine the relative importance of each parameter. In existing turbines it is possible to study the effects of certain basic plant-design characteristics on fish mortality. For example, the depth of the turbine in relation to the tailrace affects the pressure drop across the runner. Average minimum pressures are raised and cavitation is reduced by increasing the back pressure on the turbine. Additional back pressure probably can be applied at existing plants for test purposes by lowering one or more stop logs into the draft-tube gate slots. Investigations of this kind, however, relate only to future turbines, for little can be done to influence these factors in existing plants without seriously reducing efficiency.

Our first priority is to solve the problem at dams on the main stem of the Columbia and Snake Rivers. For practical purposes, all dams (except possibly one) will be completed as presently designed. Therefore, the approach now being followed by researchers concerns the specific agents of mortality and the locations of the associated structures. Suspect agents include cavitation, low pressures, shear planes of water, and contact with solid objects. The modification of structures to minimize these lethal agents is one possibility. Another possible solution is to add air to the water passing through the turbine. Rasmussen (15) demonstrated that erosion of metal by cavitation was completely eliminated by adding to the water 1% of air by volume at atmospheric pressure. Air may be pumped into turbines or introduced from the atmosphere by venting (16). The Bureau of Commercial Fisheries has installed a compressed air system in turbine No. 3 at Ice Harbor Dam (Figure 11). Evaluation of this system is in progress.

The structures responsible for fish mortality have not been identified, but the natural distribution of fish suggests which portion of the structures to suspect: the upper portion of the stay vanes and wicket gates, the blades at or near the hub, and the terminal end of the hub. Further research can be conducted in full-scale turbines to pinpoint the most important structure involved in the mortality of fish. Research in the prototype to eliminate lethal agents, however, is limited to an empirical approach; i.e., modifying structures to eliminate a hypothetical cause of death and measuring the resultant change in survival.

Because of the difficulties of working in full-scale turbines, small-scale models have been used to study how turbines might be modified to increase fish survival. Bell (14) reported, however, "It does not appear possible to extrapolate from the results of model studies to prototype structures." One problem with small-scale models is that the fish themselves cannot be scaled down.

A third approach is now under consideration: Biohydraulic studies in which small segments of suspect structures are duplicated in full scale. Full-scale fish would be subjected to these structures in full-scale water velocities. High-speed photography would aid in interpreting results, and hydraulic

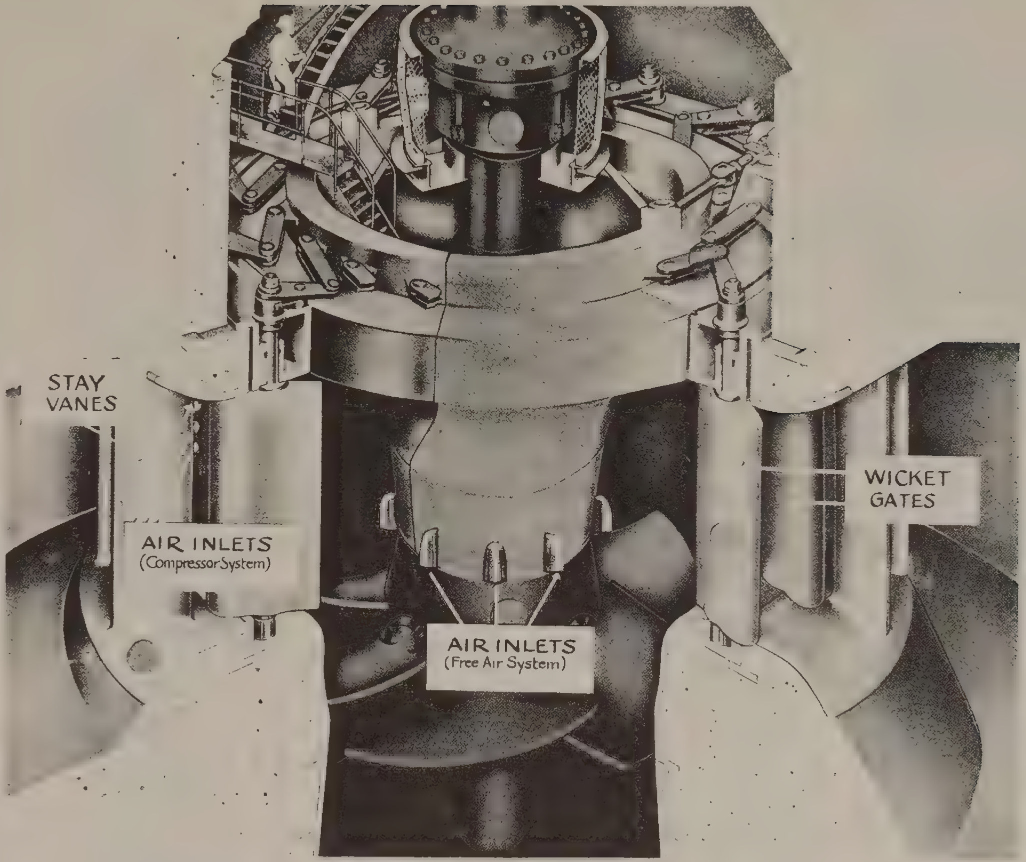
STAY VANES
AIR INLETS (Compressor System)
AIR INLETS (Free Air System)
WICKET GATES

Figure 11. Two methods for adding air to water passing through turbines: (1) Air from compressors enters each hollow stay vane and leaves from ports in trailing edge of stay vanes, and (2) high velocity flows passing faired ports in hub create zone of low pressure that sucks atmospheric air into flows near base of blades.

phenomena could be measured with precision. Tests could be conducted with small numbers of fish rapidly and at any time of the year. Costs of structural modifications and of testing would be lower than those of research in full-scale turbines. These studies should increase our understanding of how fish are killed within turbines and may lead to solutions that have not occurred to us. Tinney (17) concurs that full-scale hydraulic studies of segments of structures would provide valuable information and suggests that preliminary work with full-scale models in wind tunnels may yield much information for less cost.

Results from these full-scale model studies would be applied to a prototype turbine for final evaluation, or if the required modifications proved impractical, research could then be concentrated on controlling turbine loads and bypassing fish around turbines.

Bypassing Fish Around Turbines

The most promising direction for present research on bypassing fish appears to be related to the natural entry of fish into intake gatewells. Present efforts to devise fish-guiding methods center on intake gatewells as the initial port of entry of a bypass system. Fish would be routed from the gatewells into trash sluices or special bypasses.

Liscom (18) reported that fingerlings in gatewells will not readily locate outlets (discharge orifices leading to ice and trash sluiceways or other bypasses). We assume, however, that this problem can be easily solved, provided a large percentage of the fish can be diverted into the gatewells. The problem at hand is to find ways of increasing the number of fish that enter the gatewells. Investigations of fish-guiding methods applicable to turbine intakes are currently being conducted in Bureau of Commercial Fisheries laboratories at Seattle[3] and North Bonneville, Washington[4]. Promising results from behavioral studies at the Seattle laboratory are applied at the Bonneville laboratory in a special device that closely resembles a segment of an intake and gatewell at Ice Harbor Dam (19). Several promising leads have been developed in this research, but they are not yet ready for testing in a prototype intake.

Traveling screens are now being considered for guiding fish around turbines. Screens that are fish tight guarantee guiding, but mortality from impingement and plugging from debris are potential problems. By placing a traveling screen on an angle to flow, such as in Figure 12, fish may prevent impingement by swimming only 1.55 fps. Duration of impingement will not exceed 10 seconds because the fish will have reached the end of the screen and will be swept off. Traveling-screen migrant traps used for two seasons during spring floods on the Grande Ronde River (20) and one season on the Salmon River show the screens are self cleaning. Furthermore, the screens were

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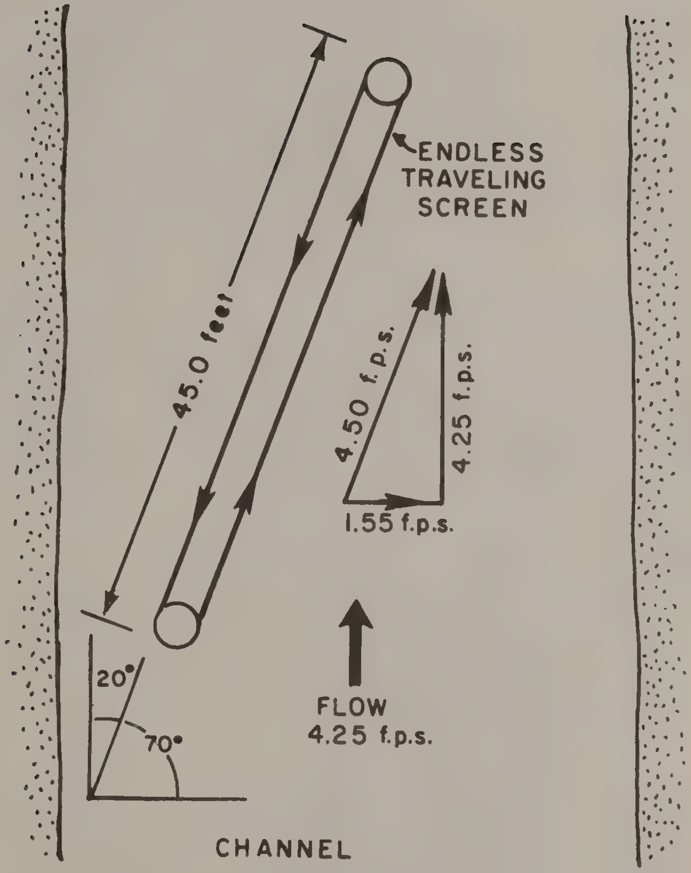
45.0 feet
ENDLESS
TRAVELING
SCREEN
4.50 f.p.s.
4.25 f.p.s.
1.55 f.p.s.
20°
70°
FLOW
4.25 f.p.s.
CHANNEL

Figure 12. Endless screen placed on angle to flow travels 4.5 fps. Three advantages obtained: (1) Fish capable of swimming 1.5 fps need not impinge, (2) duration of fish impingement will not exceed 10 seconds, and (3) plugging from debris is minimized because screen is self-cleaning.

effective in flow velocities up to 10 fps for trapping I-group salmonids. Preliminary studies indicated that O-group salmonids can be impinged for short durations without harm[5].

Present plans call for testing a small traveling screen in the simulated intake at the Bonneville laboratory. Effects of fish impingement, among other things, will be examined and if results are satisfactory, we hope to test a prototype screen in one of the turbine intakes at Ice Harbor Dam. Figure 13 shows how a traveling screen might be employed to bypass approximately 70% of the fish entering a turbine intake. The trash racks provide built-in protection from large logs. Evaluation would be accomplished with fyke nets in an intake frame and by dip netting fish out of the gatewell. Tests with and without the traveling screen in place would be conducted.

ACKNOWLEDGMENTS

Our research program has profited immensely from the aid given by numerous individuals of many fields of interest. In particular, we acknowledge Richard L. McNeely, Exploratory Fishing and Gear Research, Bureau of Commercial Fisheries, Seattle, Washington, who provided the initial stimulus for development of the first funnel net used at Bonneville Dam, and Ivan J. Donaldson, U. S. Army Corps of Engineers, Bonneville, Oregon, who advised us in many phases of our early research.

For particular contributions, including the review of this manuscript, we thank Charles E. Behlke, Institute of Water Resources, University of Alaska; Milo C. Bell, College of Fisheries, University of Washington; Donald R. Burns, Allis-Chalmers Manufacturing Co., Portland, Oregon; Kenneth E. Davis, Reed College, Portland, Oregon; Roy Malm, Brown Electromeasurements Corp., Kirkland, Washington; Gerald J. Paulik, College of Fisheries, University of Washington; Chester T. Scott, U. S. Army Corps of Engineers, North Pacific Division, Portland, Oregon; and E. Roy Tinney, Water Research Center, Washington State University.

Fishery research in full-scale turbines poses many problems to those who own and operate the plants. Disruptions in regular work schedules to accommodate experimental work are common. The many valuable suggestions received from plant personnel have enhanced materially the progress of our research. We are grateful to personnel of the Army Corps of Engineers at Bonneville Dam, The Dalles Dam, McNary Dam, and Ice Harbor Dam, and to personnel of the Grant County Public Utility District at Priest Rapids Dam for the cooperation and aid they have given us in our work.

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[5] Daniel W. Bates, Program Leader, Fingerling Collection Studies, Bureau of Commercial Fisheries, 811 N.E. Oregon Street, P. O. Box 4332, Portland, Oregon 97208.

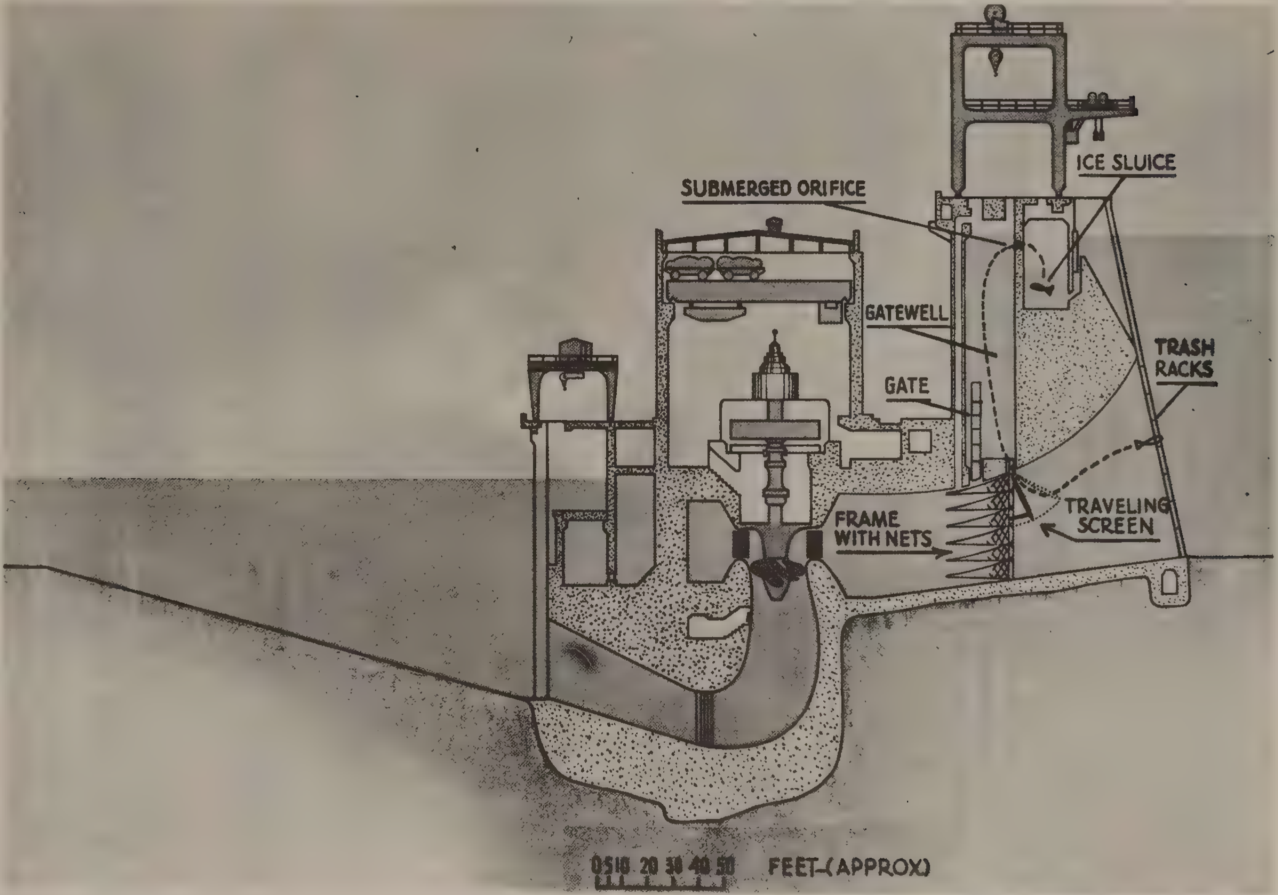
SUBMERGED ORIFICE
ICE SLUICE
GATEWELL
GATE
TRASH RACKS
FRAME WITH NETS
TRAVELING SCREEN
0 5 10 20 30 40 50 FEET-(APPROX)

Figure 13. Section through typical turbine intake showing location of proposed traveling screen for diverting 70 percent of the fingerlings up into gatewells.

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Reprinted in Canada from CANADIAN JOURNAL OF GENETICS AND CYTOLOGY,—Journal Canadien
de Génétique et de Cytologie, Volume IX, Number 4, December 1967

CHROMOSOME COMPLEMENT OF THE AMERICAN OYSTER *CRASSOSTREA VIRGINICA*, AS SEEN IN MEIOTIC AND CLEAVING EGGS

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U.S. Bureau of Commercial Fisheries Biological Laboratory Milford, Connecticut

Introduction

Exploratory cytogenetic investigations have been initiated on the commercially valuable American or Eastern oyster, *Crassostrea virginica* Gmelin. Although marine animals played an important role in early cytological studies of chromosomes, cell division, and early development (Wilson, 1953), these forms have not been used so much in recent genetic and cytogenetic researches. There is little cytogenetic information on most of the invertebrates aside from the insects. Karyological and allied studies of the oyster and related groups could prove of considerable theoretical interest in addition to their applied use.

An analysis is presented here of the chromosome complement of *C. virginica*, as seen in the meiotic, fertilized, and cleaving eggs of oysters taken from the vicinity of the harbor of New Haven, Connecticut; the eggs were spawned and fertilized in the laboratory.

Materials and Technique

All oysters used in this study were from wild *C. virginica* Gmelin stock local to the vicinity of the harbor of New Haven, Connecticut. With the exception of eggs at diakinesis, all eggs and sperm were from laboratory-induced spawning of adult male and adult female oysters (see Loosanoff and Davis, 1963). Eggs at diakinesis and late diplotene were obtained by stripping the female gonads. Several million eggs can be obtained from one ripe female. The oviparous *Crassostrea* species are usually not hermaphroditic. *C. virginica* is reported to be protandric (Coe, 1932).

Best preparations of the meiotic, fertilized and cleaving eggs were made when fixation was simply in Carnoy (3:1). Chromosome squashes were made in 1 to 2% orcein in 45 to 60% acetic acid. Sometimes fatty yolk had to be removed from mature eggs by irrigating them with chloroform.

For induction of colchicine metaphases in cleaving eggs, a stock solution of 0.1% colchicine in filtered sea water was added to the sea water containing the eggs to give a final drug concentration of about 0.02%. Time of treatment was usually 15 to 20 minutes. This time is not sufficient to allow one colchicine-mitotic division to be completed should this be possible in this material. Tetraploid restitution nuclei, then, could not contribute to the metaphase cells analyzed in treated embryos. Use of colchicine made feasible the formal karyotyping of this methodologically difficult material.

Examination of chromosomes was usually with the 100X Zeiss Neofluar phase-contrast objective, and Zeiss 12.5X Kpl oculars. Chromosome sets were photographed in the center of the field. Negatives were projected through a Simmon Omega D2 enlarger, enlarged 6.4X — total magnification of 1 μ to 4.0 mm. Each chromosome arm was delimited and measured from its end to the centromere zone.

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[1] The helpful comments and suggestions of Professor Albert Levan, Institute of Genetics, Lund University, Lund, Sweden, are gratefully acknowledged.

Manuscript received Sept. 11, 1967.

Can. J. Genet. Cytol. 9: 845-856. 1967.

Observations

Meiotic Chromosomes of C. virginica

Eggs fixed after spawning but before fertilization and those fixed just after fertilization are almost all at metaphase I of meiosis; a few cells sometimes are at diakinesis or prometaphase I. The sperm head or male pronucleus can also be discerned in the egg from the time of fertilization until fusion of the male and female chromosomes on the first cleavage spindle. All the *C. virginica* bivalents are homomorphic and isopyknotic. Metaphase I and prometaphase I chromosomes were observed and counted in hundreds of eggs from at least 15 different, female American oysters. Every animal had 10 pairs of chromosomes. An occasional aneuploid egg was detected. Bivalents are seen especially well in diakinesis and prometaphase I eggs. Chiasmata are present. A diakinesis stage is shown in Fig. 1.

Ten chromosomes were counted at anaphase I (Fig. 2), at metaphase II (Fig. 3), and in each anaphase II group. At metaphase II the chromosomes are usually highly contracted, darkly staining bodies, often loosely associated two-by-two or in larger groups. Their combined, total length in one typical metaphase was only 13 μ. The male and female chromosomes were also observed and counted just before their orientation on the first cleavage spindle with the resulting fusion of the two chromosome groups. Each group had 10 chromosomes. No structural differences were observable between chromosomes of the two groups in different embryos. One set is often more contracted than the other. This more contracted condition seemed characteristic of the chromosomes from the male pronucleus. None of the chromosomes exhibited differential heteropyknosis. Division of the first polar body in fertilized eggs also revealed 10 isopyknotic chromosomes. When centromere position was evident in the chromosomes at these stages of meiosis and fertilization, the chromosomes could be classified as metacentrics and submetacentrics, or subtelocentrics. Variation in length of the 10 different chromosomes is apparent but not great.

Meiosis in *C. virginica* is of the usual type, at least in most eggs spawned and fertilized under ordinary laboratory conditions. No atypical phenomena regularly appear in meiosis, fertilization, and early cleavage of the egg. Some eggs, however, show unusual or abnormal behavior at meiosis and fertilization. Generally, non-fertilized eggs remain at metaphase I. A full account of meiosis, normal and irregular, is to be published.

Cleavage Chromosomes of C. virginica

The cleavage chromosomes from about 10 different *C. virginica* crosses were examined.

Counts were first made of the chromosomes in fertilized, cleaving eggs of *C. virginica* (2- to 32-cell stage) which had not been treated with colchicine. Estimates of 20 chromosomes were obtained from eggs flattened only enough to discern individual chromosomes in the various intact cells. Exact counts of 20 were made on squashed cells. All stages of mitosis were examined (see the

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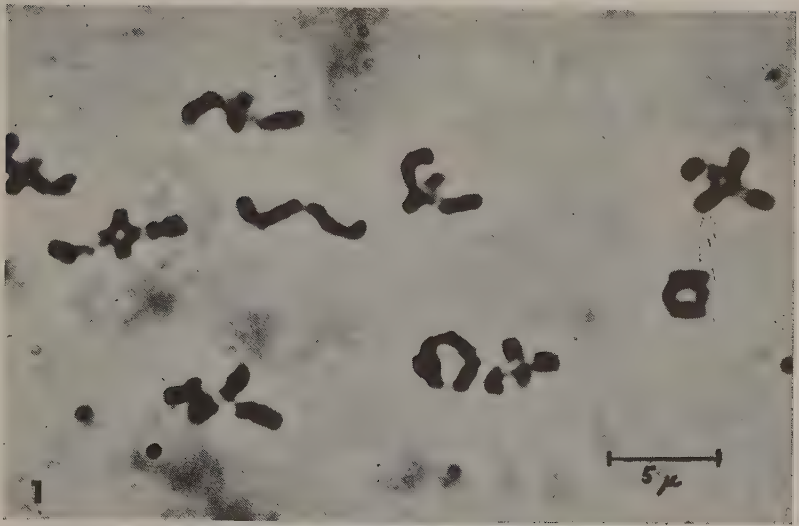
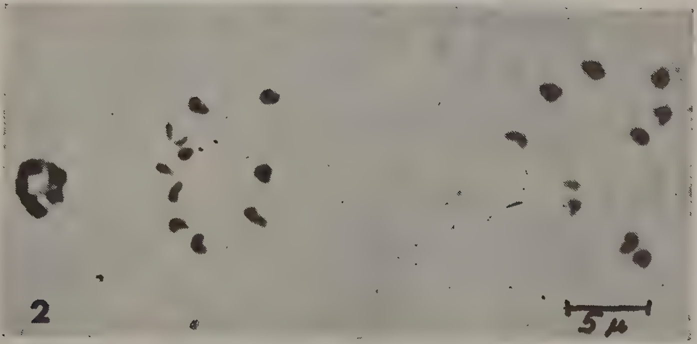
Fig. 1. Ten pairs of diakinesis chromosomes of an unfertilized egg of *C. virginica*. Fig. 2. Late meiotic anaphase I in a fertilized *C. virginica* egg showing the reduced number of chromosomes (and the male nucleus). Fig. 3. The 10 rounded, contracted female chromosomes of meiotic metaphase II in a fertilized egg of *C. virginica*. (Two chromo somes are lying close together.)


1
5 μ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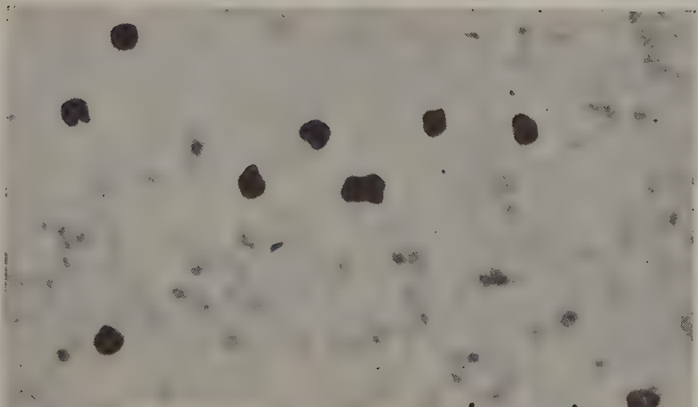
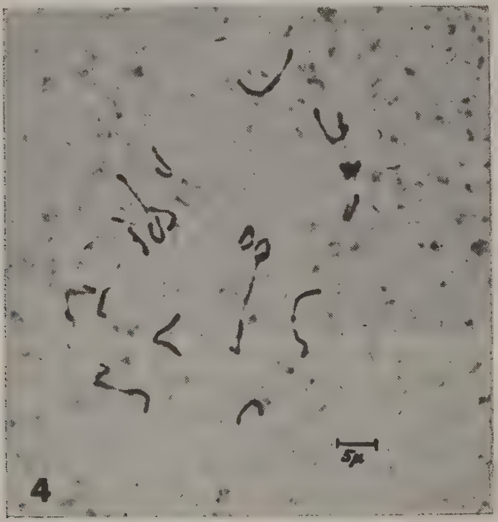

3
5 μ

prophase of Fig. 4 and the anaphase, Fig. 5). Again, a few aneuploids appeared, as at female metaphase I, as well as a low but appreciable frequency of haploids. The first, outermost polar body was in full metaphase during early cleavage. Care must be taken not to confuse this haploid remnant of meiosis with cleavage divisions of the embryo.



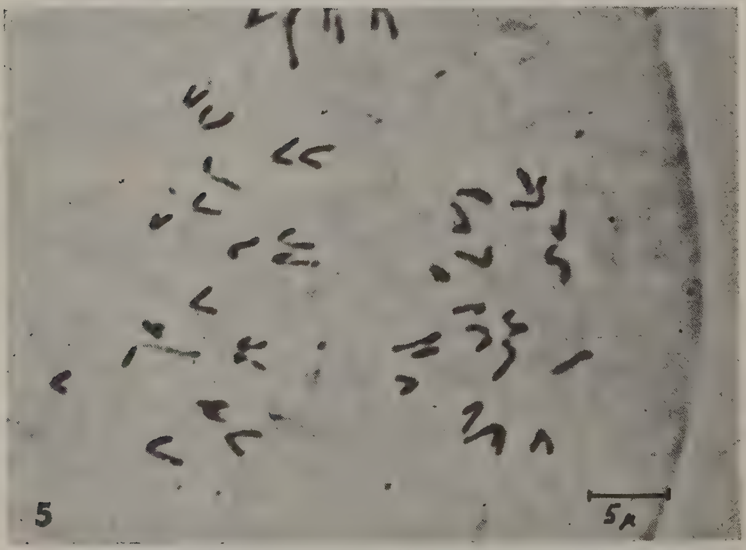


Fig. 4. Late prophase of an early cleavage of *C. virginica* showing about 20 chromosomes. Fig. 5. Late anaphase of an early cleavage in *C. virginica* with an approximate number of 20 bi-armed chromosomes visible in each of the two anaphase groups.

Cursory examinations were made of the mitoses of older embryos up to the trochophore stage, and the observations on chromosome number agreed with those made at earlier stages.

Cleavages treated with colchicine were particularly appropriate for chromosome counts and show 20 chromosomes very clearly. One characteristic colchicine-metaphase group is shown in Fig. 6. Counts were made on

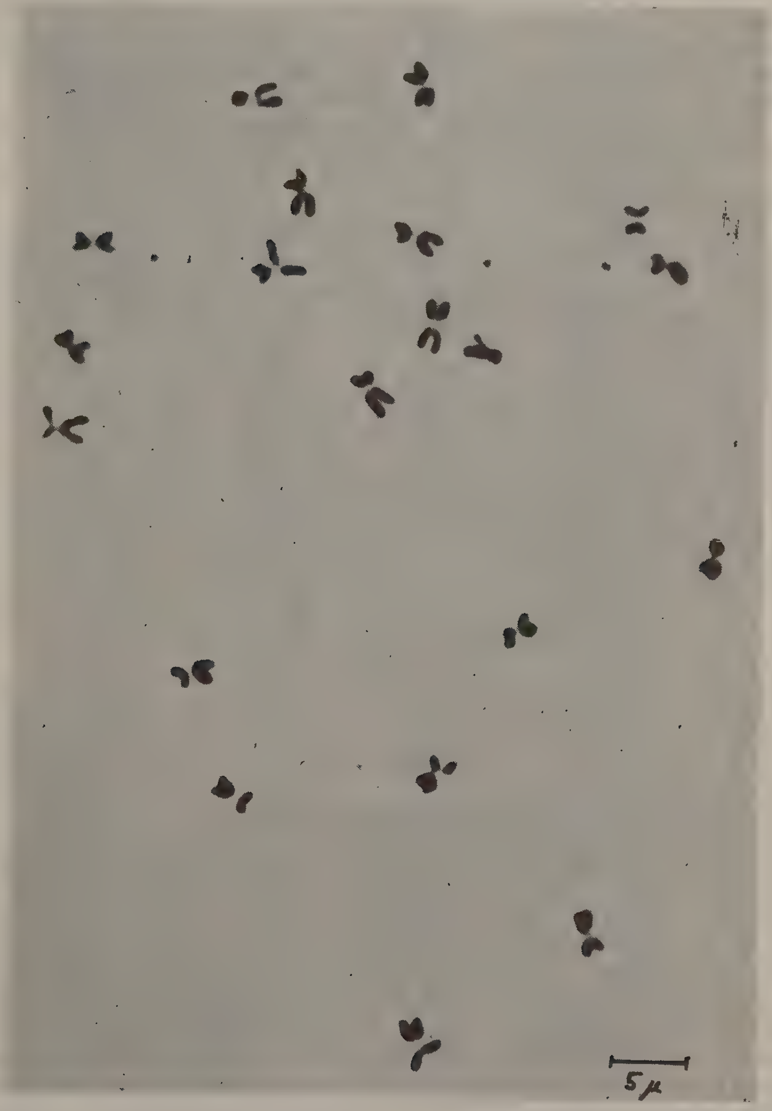


Fig. 6. Colchicine-metaphase chromosomes of an early cleavage in *C. virginica* demonstrating the chromosome number of 20.

hundreds of different embryos from these several crosses of different parents. In addition, many counts were made on several cells within single embryos. The number was consistent for all cells of these early embryos, excluding the polar bodies.

Cleavage chromosomes, both colchicine-treated and non-treated, are also all isopyknotic. They are generally less contracted than the chromosomes of metaphase II of the egg or those developed from the male pronucleus.

Depending, of course, on the exact stage of the treated or non-treated metaphase, the length of the cleavage chromosomes can range about 1 μ in some cells and about 7 μ in other cells. Centromere positions of the chromosomes of both normal and colchicine-metaphase appear to be median, submedian, or perhaps subterminal in some chromosomes.

In some cells one or two of the longest median chromosomes bear a secondary constriction near the end of one of the arms.

Karyotype Analysis of the C. virginica Cleavage Chromosomes

Every one of all the 20 chromosomes in 18 colchicine-metaphase, early-cleavage cells of *C. virginica* was measured. The 18 cells represent 17 different embryos. The longest chromosomes in these cells ranged from 1.5 to 3.0 times the length of the shortest chromosome. Arm ratios varied between about 1:1 and 1:3. It is indeed one of the longest median chromosomes of the complement that bears a secondary constriction which is about two-thirds of the distance from the centromere to the end of the chromosome. Although not often observed at colchicine-metaphase this constriction, when present, is unmistakably clear.

The most similar of the 20 chromosomes of each of these 18 colchicine-metaphases were arranged into pairs, and the pairs arranged according to decreasing length. Total measured length, measured arm ratios, and general morphological appearance were the criteria used for pairing. As expected from sight examinations of the chromosomes, their lengths grade from longest to shortest. The shortest chromosomes are distinguishable from the longest, but between these extremes are several chromosomes the lengths of which differ slightly, if at all. With few exceptions the chromosomes could be easily arranged into pairs. This is obviously due more to the available number of choices of similar, but not homologous chromosomes than to any lack of the usual inter-homologue variability characteristic in other species studied karyologically (see Discussion). None of the exceptional, poorly matching pairs occurred consistently in any particular position in the 18 series of chromosomes arranged according to length. Such discrepancies, then, could not be attributed to any morphologically dissimilar sex chromosomes. In Fig. 7 are shown four series of chromosomes arranged according to length and, also, according to centromere position.

Following this tentative pairing off of individual chromosomes the linear dimensions and photographic prints of all 18 cells were considered as a whole to determine the general pattern of the *C. virginica* chromosome complement and the extent of variability due to non-synchronous contraction of individual chromosome arms. These general considerations confirmed the impression gained from sight examination of the cleavage and meiotic chromosomes that these chromosomes are approximately median and submedian. In the 18 cells the number of chromosomes with measured arm ratios of more than 1.5 is from

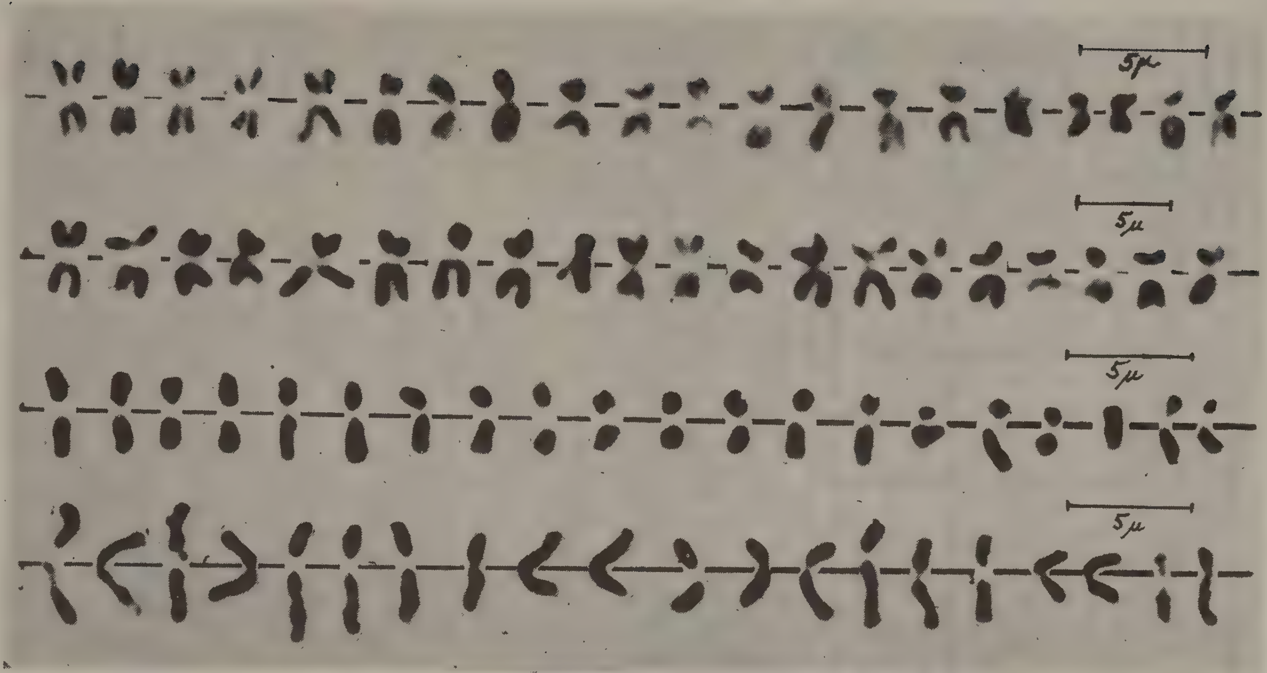


Fig. 7. Four karyotyped colchicine-metaphases of early cleavages in *C. virginica.* Chromosomes are arranged according to length and arm ratio.

4 to 11. A tendency exists, however, for four submedian pairs to occur in each cell complement, which are relatively more disproportionately armed than the rest of the chromosomes of that cell. These four all have arm ratios of about 2 on the average. One occurs among the longest chromosomes, one among the shortest, and two in the middle group of chromosomes in series arranged according to length. This distribution makes it unlikely that these submedian chromosomes are simply extreme examples of differential arm contraction occurring at random in different cleavage cells among several different, nearly metacentric chromosomes.

Measurement of the chromosomes of a non-colchicinized female metaphase II, a cleavage anaphase, and a non-colchicinized cleavage metaphase revealed the same trends indicated above in the 18 colchicine-metaphases. Differences in length measurements of two colchicine-metaphases in a single embryo revealed the cell-to-cell variability of these measured complements to be about the same as embryo-to-embryo variability.

The averaged lengths and arm ratios of the 10 pairs of chromosomes of the 18 colchicine-metaphases under analyses are given in Table I. Mean length extended from 3.3 ± 0.18 to 2.0 ± 0.10 μ, or from 6.4 ± 0.14 to 3.8 ± 0.07 per cent of the total length of the diploid complement. The most equal of the mean arm ratios was 1.1 ± 0.02, the most unequal, 2.0 ± 0.03.

A tentative idiogram of the American oyster complement has been drawn (Fig. 8) on the basis of the general nature of the complement indicated by examination and these measurements of individual metaphases, observation and analysis of a cleavage anaphase, and a non-colchicinized, cleavage metaphase. The idiogram is arranged generally according to chromosome length. The four strongly submedian chromosomes are placed at the end of the group of chromosomes they most closely match in total length. Assuming that the long

TABLE I

Mean length and arm ratio of 18 early cleavage, colchicine-metaphases from 17 different embryos

Chromosome number	Mean length in microns	Mean length as per cent total length of diploid complement	Mean arm ratio
I – II[1]	3.3 ± 0.18 3.1 ± 0.13	6.4 ± 0.14 5.7 ± 0.07	1.1 ± 0.02 1.2 ± 0.02
III	3.2 ± 0.18	6.1 ± 0.11	1.9 ± 0.20
IV – VI	2.7 ± 0.13 2.5 ± 0.13 2.3 ± 0.08	5.2 ± 0.07 4.8 ± 0.06 4.4 ± 0.08	1.2 ± 0.04 1.2 ± 0.03 1.2 ± 0.07
VII – VIII	2.4 ± 0.10 2.7 ± 0.13	5.2 ± 0.09 4.7 ± 0.06	1.7 ± 0.10 1.9 ± 0.06
IX	2.0 ± 0.10	3.8 ± 0.07	1.3 ± 0.10
X	2.1 ± 0.10	4.0 ± 0.10	2.0 ± 0.03

[1] One of these two bears a secondary constriction. Therefore, I and II can be distinguished from one another in some cells, but not in all cells measurable.

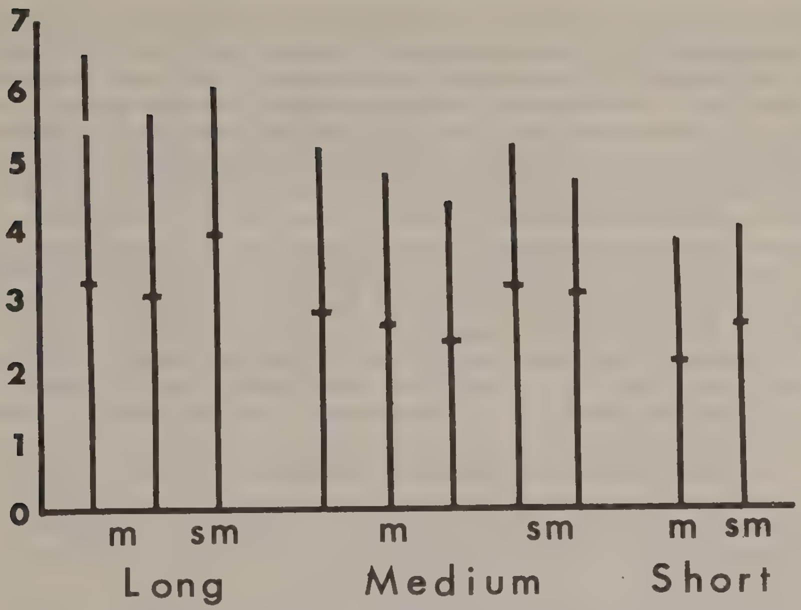


Fig. 8. Working idiogram of the colchicine-metaphase, cleavage chromosomes of *C. virginica.* Designation of these idiogram chromosomes as m (centromere in median region), and sm (centromere in submedian region) follows the suggestions of Levan, Fredga and Sandberg (1964) for chromosome nomenclature based on centromeric position.

median, secondarily constricted chromosome is always the same chromosome, its identification should be positive. The two next longer chromosomes of the idiogram might be distinguishable on the basis of their arm ratios, approximately 1 and 2. The next five chromosomes are of similar, if not identical length. The last two have relatively strongly disproportionate arm ratios, again about 2. One of the shortest chromosomes is submedian (arm ratio about 2); the other, approximately median. There is no evidence for any morphologically different male and female sex chromosomes.

Discussion

Since the development of improved techniques for chromosome preparations, little has been published on the chromosome cytology of the mollusks with the exception of the Gastropoda (Burch, 1964). Makino (1951) listed chromosome numbers for the phylum Mollusca from $2n$ of 10 to 62, and $1n$ from 6 to 31 chromosomes. For the class Pelecypoda to which the oysters belong chromosome numbers are cited only for clams from the genera *Cumingia* and *Mactra* ($1n = 12$, 16 and 18). Menzel and Menzel (1965) reported chromosome numbers of $n = 19$, $2n = 38$ for two species of hard clams, *Mercenaria mercenaria* and *M. campechiensis*, and their hybrids.

In a study on spermatogenesis in the Pacific oyster, *Ostrea lurida,* Coe in 1931 illustrated 10 pairs of chromosomes at prophase I of meiosis and 8 and 10 at second meiotic metaphase. In the text he stated that the chromosome number could not be definitely determined because of the crowded condition of the metaphase and anaphase plates in the tissue sections. Cleland (1947) reported on oogenesis in the Sydney rock oyster, *O. commercialis*. He stated briefly that he counted 8-11 chromosomes in sections of two- to four-cell stages in fertilized eggs. Ten was the most common number. Metaphase plates proved difficult for chromosome counts because of the small size of the chromosomes and their close packing on the spindle. On the basis of sections of cleaving eggs Galtsoff (1964) in his treatise on *C. virginica* reported counting 7 to 10 chromosomes at the beginning of anaphase.

The cited diploid counts of 10 for *C. virginica* might be attributable to some abnormality of meiosis and fertilization, or to a form of parthenogenesis resulting in haploid embryos. Although the haploids or abnormals might represent only a small percentage of all the cleavages on the slides, they would be preferentially chosen for counting, since 10 chromosomes can certainly be distinguished in this material more easily than can 20. These $2n$ counts of 10 could also have been based on division of the first haploid polar body which occurs during cleavage.

The diploid number of 10 tentatively ascribed by Rosenfield to several oyster species (see citation in Ahmed and Sparks, 1967) is most likely due to the mistaking in this methodologically difficult material of polar body divisions for diploid embryo cells (personal communication with the author). Rosenfield, nonetheless, was the first to indicate the probable uniformity of chromosome number among several oyster species. This recent report (Ahmed and Sparks, 1967) of another still preliminary examination of chromosomes of two oyster species, *Ostrea lurida* and *Crassostrea gigas*, gives diploid numbers of 20 for both.

The chromosomes of five other commercial and non-commercial oyster species have been cursorily examined in the course of the study reported here on the American oyster (Longwell and Stiles, unpublished). The species include *Crassostrea gigas*, *C. rhizophorae*, *Ostrea edulis*, *O. lurida*, and another *Ostrea* species tentatively identified as *O. equestris*. All appear to have the same chromosome number as *C. virginica*, $2n = 20$. Estimates of chromosome number in these oysters came variously from meiosis, cleavage, gonadal, and gill mitoses. Mitotic chromosomes of these species do not look markedly different from those of the American oyster. The general difficulty of the material, though, requires a detailed karyotype analysis of each species. No representative of the third and only other oyster genus, *Pycnodonte*, has yet been examined cytogenetically.

Colchicine and normal metaphase figures in gill and gonad tissue of *C. virginica* have also shown a chromosome number of 20 in numerous instances in fixations from several different animals. In other, and related studies 20 chromosomes have been counted in different tissues of larvae and young spat. Nonetheless, in some small cells 10 small bodies were counted, presumably chromosomes. Almost all of these cells were from animals in which other cells had distinctly displayed 20 chromosomes. Sometimes these 10 chromosomes appeared as 5 pairs. Different tissue cells with 20 chromosomes sometimes also displayed what could be interpreted as paired chromosomes. As noted earlier, these chromosomes tend to associate at female meiotic metaphase II. The general difficulty of this material, the small size of the oyster chromosomes and, especially, our limited knowledge of genetic aspects of its development caution against premature interpretations of observations as somatic reduction and pairing without first improving chromosome methodology and conducting careful study. Study of meiosis in the male gonad of *C. virginica* is unfortunately hampered by the small cell size of the spermatocytes.

Some of the difficulty in the description and measurement of the 10 pairs of oyster chromosomes surely comes from personal error and errors inherent in the karyotyping technique. Much of the discrepancy, however, must arise from the general and well-known asynchrony of contraction of the chromosomes. This asynchrony even affects the two homologues of a single chromosome, and the two arms of individual chromosomes, and may be exaggerated by the use of colchicine (Bajer, 1959; Lima-de-Faria, 1959; Sasaki, 1961). However there was no evidence that colchicine treatment obscured any real and potentially useful differences among oyster chromosomes; centromere positions were often better defined in treated than in non-treated cells. Comparison of different types of division figures and of cells of different cleavage mitoses in the oyster might well further accentuate the pattern of differential contraction. Possibly the shortness of these oyster chromosomes further contributes to their variable contraction.

Although some of the *C. virginica* chromosomes should be positively identifiable under some conditions, others will be difficult or impossible to distinguish from one another on the basis of sight examination and linear dimensions. Nonetheless, careful examination and measurement of a number of cells should provide information on the general pattern of the karyotype, as has been done for the mouse chromosomes (Levan, Hsu and Stich, 1962) which approximate in size those of the oyster. More critical karyotype analyses of the chromosomes of *C. virginica* and comparisons of the chromosomes of different oyster species should be much facilitated by the development recently of an improved method for extracting yolk from the oyster eggs prior to making chromosome preparations (Longwell and Stiles, in press).

The ten chromosome pairs of the oyster might, of course, well be further distinguished by their nucleolar associations; by autoradiographic study of their sequence of DNA synthesis with tritiated thymidine (Schmid, 1965); and by accentuating or inducing different secondary constrictions through various means (Kihlman and Levan, 1951; Cohen, 1963; Sasaki and Makino, 1963; Hampel and Levan, 1964).

Summary

At spawning and just after fertilization, eggs of the American oyster, *Crassostrea virginica,* displayed 10 homomorphic, isopyknotic bivalents at meiotic metaphase I with chiasmata. Ten chromosomes were counted in each anaphase I and early telophase I group of the eggs. At metaphase II there were 10 highly contracted chromosomes. Ten chromosomes were also contained in the male pronucleus. No structural differences were observable between the male and female set of chromosomes of different embryos, all of which were isopyknotic. The first polar body, which is in full metaphase during early cleavage, also showed the reduced number of 10. No unusual nuclear phenomena were observed regularly associated with female meiosis, fertilization, or early cleavage. At mitosis and colchicine-metaphases of fertilized, cleaving eggs there were 20 chromosomes. Lengths of early cleavage chromosomes at c-metaphase ranged from about 2 to 3.5 μ. Most of them were metacentric.

One of the longest chromosomes, one of the shortest, and two among the chromosomes of intermediate length were submetacentric. These chromosomes could be arranged into 10 homomorphic pairs in the several embryos studied.

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G142. Bacteriological Studies of *Crassostrea virginica* in Chesapeake Bay. T. E. LOVELACE, H. TUBIASH, and R. R. COLWELL. Georgetown University, Washington, D.C.

A study of the natural bacterial flora of invertebrate animals of Chesapeake Bay is currently underway. Animal, water, and mud samples, taken at monthly intervals from two areas, Eastern Bay, a commercial oyster harvesting area, and Pocomoke Sound, where drastic mortalities occur annually in the oyster population, have been examined for total viable counts of aerobic, heterotrophic bacteria. Animals yielded total counts of 10^3 to 10^4 bacteria per milliliter of mantle fluid and 10^4 per gram of gill tissue; seawater yielded 10^2 and mud 10^4 to 10^5 organisms per milliliter. Counts on distilled water-agar medium were of an order of magnitude less than on agar medium made up with water from the sampling site as diluent. The qualitative distribution of the flora differed markedly. A total of 157 pure cultures isolated from the count plates have been subjected to taxonomic analysis by computer. Gram-negative, asporogenous, rod-shaped bacteria prodominated. Eastern Bay samples, overall, consisted of 37% *Cytophaga/Flavobacterium*, 25% *Vibrio*, 16% *Pseudomonas*, 16% *Achromobacter*, and 6% other species; Pokomoke Sound samples consisted of 46% *Vibrio*, 22% *Pseudomonas*, 13% *Achromobacter*, 5% *Corynebacterium*, 3% *Cytophaga/Flavobacterium*, and 3% other species. The qualitative differences were consistent from sample to sample within the geographical areas studied. The mortalities of the invertebrate animal populations of Chesapeake Bay may be related to the incidence of bacterial types on the animal or in the surrounding environment.

Effects of Prolonged Exposure to Sevin® on an Estuarine Fish, *Leiostomus xanthurus* Lacépède

by JACK I. LOWE
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Gulf Breeze, Florida[1]

Introduction

Sevin is the registered trademark of the synthetic carbamate insecticide, 1-naphthyl N-methylcarbamate. It is also known as carbaryl. This insecticide is toxic to a wide variety of insects as both a contact and a stomach poison. It is reported to be effective against many insects which have become resistant to chlorinated hydrocarbon and phosphate insecticides. Sevin is also toxic to crustaceans and has been used to a limited extent in marine environments to control burrowing shrimp, Callianassa

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® Registered trademark, Union Carbide Corp., New York, N. Y.

[1] Contribution No. 77

Bulletin of Environmental Contamination & Toxicology,
Vol. 2, No. 3, 1967, published by Springer-Verlag New York Inc.

californiensis and *Upogebia pugettensis* (1). The digging activities of these crustaceans make the substrate in some areas unsuitable for oyster production.

Sevin has a relatively low degree of mammalian toxicity and is generally classified among the safer pesticides now in use (2). This comparatively low acute toxicity also applies to fish. The amount of Sevin required to produce a 48-hr. LC_{50} (concentration lethal to 50% of test population) in rainbow trout, *Salmo gairdneri*, and longnose killifish, *Fundulus similis*, is about 250 times greater than that of DDT (3). Katz (4) tested 95% Sevin and reported the 48-hr. TL_m (median tolerance limit) for coho salmon (*Oncorhynchus kisutch*), rainbow trout, bluegill (*Lepomis macrochirus*), and threespine stickleback (*Gasterosteus aculeatus*) to be 0.99, 1.35, 5.30, and 10.45 p.p.m., respectively. Stewart, Millemann, and Breese (5) reported 80% Sevin to give a 24-hr. TL_m of 6.7 p.p.m. for the threespine stickleback. They also found 1-naphthol, a hydrolytic product of Sevin, to be more toxic than Sevin to fish.

In the present study juvenile spot, *Leiostomus xanthurus*, survived 5 months of continuous exposure to 0.1 p.p.m. Sevin in flowing sea water. I am unaware of previous studies in which marine fish were chronically exposed to Sevin or other carbamate insecticides.

Materials and Methods

This laboratory experiment was conducted in a constant-flow system in which fish were exposed to continuously renewed solutions of Sevin in sea water. I put 200 juvenile spot, averaging 18 mm. standard length, in each of two fiberglass-lined wooden tanks. These tanks had a capacity of about 180 liters and measured 30 cm. in width, 25 cm. in depth, and 244 cm. in length. A constant flow of 100 liters of unfiltered sea water per hour passed through each of the tanks. Average monthly water temperatures during the exposure period (March 24 - August 29, 1966) varied from 16° to 29°C. and average monthly salinities ranged from 24 to 30 p.p.t. The fish were fed daily on a mixture of ground fish and dog food.

A Sigmamotor[1/] pump equipped with a Zero-Max speed changer continuously metered (2 ml./min.) a stock solution of Sevin into one of the tanks to make a solution of 0.1 p.p.m. (milligrams per liter) Sevin in sea water. The other tank of fish served as a control. The 0.1 p.p.m. concentration was selected on the basis of results from preliminary screening tests in which 1.0 p.p.m. Sevin killed 60% of a population of spot after 12 days of

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[1/] Trade names referred to in this publication do not imply endorsement of commercial products continuous exposure. I prepared 18 liters of the stock solution weekly from 1.5 grams of Sevin (98% purity), 0.5 ℓ. of acetone, and 17.5 ℓ. of tap water (pH 7.2). The small amount of acetone helped dissolve the Sevin. The reported solubility of Sevin in water is less than 99 mg./ℓ.

Fish surviving the chronic exposure to Sevin were examined for possible pathology and changes in enzyme levels. Other survivors were subjected to drastic salinity changes to test their osmoregulatory ability.

Growth and Mortality

The fish that survived the chronic exposure to Sevin exhibited no symptoms of pesticide poisoning during the 5 months. Mortality was about 65% in both control and experimental groups. I believe that this high mortality was due to overcrowding and the limited amount of sea water flowing through the tanks. I was forced to terminate this experiment after 5 months because of a failure in the salt-water system which resulted in the death of the remaining control fish. Growth rate of the Sevin-exposed fish was comparable to that of controls.

Histopathological Examination of Fish

Five spot that survived the 5-month exposure to 0.1 p.p.m. Sevin were examined by Dr. E. M. Wood, consulting pathologist, to identify possible pathological changes. He also examined unexposed spot and five "positive control" spot from the survivors (50% of a test population) of a 13-day exposure to 1.0 p.p.m. Sevin.

Dr. Wood's report was negative in most respects. The positive controls showed no histologic lesions and he could not separate them from the unexposed fish. The report on the chronically exposed fish was as follows:

"I am able to separate the group on 0.1 part per million of Sevin from both of the two previous groups, and this separation is based on central nervous system lesions. Unfortunately, there is an excellent possibility that these lesions have nothing to do with the Sevin exposure. As you will recall from my report of your fish exposed to 2,4-D, parasitism was described in the positive controls consisting of a sporozoan-like organism in the brain tissue. In the present experiment, all five of the fish exposed to Sevin for 5 months show this brain parasitism which is completely absent in the other two groups. In these fish, some tissue reaction has occurred to these parasites consisting of an inflammatory reaction involving in some cases both the meninges and the substance of the brain itself. I would infer from these changes that you may observe symptoms suggesting central nervous system damage and, in addition, mortality which you may incorrectly identify with the Sevin treatment. It is possible, of course, that the exposure to Sevin has in some way reduced the resistance of this group to infestation by this parasite. The alternative indicates that the absence of these organisms in your control groups makes questionable the validity of the controls, as such.

"We have previously examined rainbow trout exposed to Sevin up to 1250 parts per billion for 21 days. These fish showed nonspecific changes in both gills and visceral adipose tissue. Such changes are lacking in your specimens."

It is unfortunate that specimens of the true control fish were not available for histological comparison with the Sevin-exposed fish.

Enzyme Activity

Some of the carbamate insecticides, like the organophosphates, are cholinesterase inhibitors. O'Brien (6) reported that the carbamates with anticholinesterase activity appear to fall into two well defined groups. Those which are ionic or strongly basic are very toxic to mammals but almost completely ineffective against insects, whereas those which are not ionic or ionizable may have good insect toxicity and are often less toxic to mammals than to insects. Sevin is in the latter group.

Weiss (7) showed that fish-brain acetylcholinesterase is inhibited in vivo by many of the organophosphorus insecticides at concentrations of 0.1 mg./ℓ. and lower. To determine the brain-enzyme activity of the fish used in this experiment, I sacrificed five spot from each tank after about 2 1/2 months and at the end of the 5-month exposure. Brain cholinesterase (ChE) levels of the spot were measured by the technique described by Holland and Lowe (8). Brain ChE of the fish after 2 1/2 months was only slightly inhibited (about 83% of normal), and at the end of 5 months was within the normal range of activity for spot. Brain ChE of spot exposed to a near-lethal concentration (1.0 p.p.m.) of Sevin for 13 days was 68% of normal. Compared to many of the organophosphorus insecticides, Sevin appears to be a rather mild cholinesterase inhibitor in fish.

Salinity Tolerance

Spot surviving the chronic exposure to Sevin were subjected to rapid increases and decreases in salinity to determine any change in their osmoregulatory ability. Unexposed spot received the same treatment. We observed no differences in reactions between the exposed and unexposed fish. Both groups of fish tolerated a direct transfer from water of 30 p.p.t. salinity to water of 50 p.p.t. salinity. Other specimens were transferred directly from water of 28 p.p.t. salinity to tap water. Neither group tolerated the tap water longer than a few hours.

Acknowledgments

I thank the staff of the Gulf Breeze Biological Laboratory for their technical assistance and advice. H. T. Holland, of this laboratory, performed the brain-enzyme analyses. Dr. E. M. Wood of E. M. Wood Diagnostic Laboratories, Tacoma, Washington, was employed to make the histopathological examinations.

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SEASONAL VARIATION OF TEMPERATURE AND SALINITY AT 10 METERS IN THE CALIFORNIA CURRENT

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INTRODUCTION

The seasonal variation of temperature and salinity at 10 meters in the California Current is examined from the CalCOFI[1] data record, 1950–62. The CalCOFI station pattern off California-Baja California (Figure 1) has been occupied repeatedly since 1950. Surveys have been conducted on almost a monthly schedule although only a portion of the station pattern was covered each time. Only four surveys were conducted in 1961 and 1962. The sampling frequency of salinity for 1950–62 is shown in Figure 2. At some of the stations temperature was measured a few more times than salinity. Harmonic curves, comprised of the annual and semiannual components, were fitted to each station record by regression analysis using the method of least squares. The harmonic curves provide the description of seasonal variation. Along with the regression analysis are descriptive statistics.

The California Current System

The California Current is the eastern limb of the anticyclonic gyre that dominates the North Pacific Ocean. It is a broad sluggish current characterized by cool, low-salinity water. Warm high-salinity water is found to the west (central North Pacific) and south (vicinity of the Gulf of California). Upwelling along the coastal boundary of the current introduces cool, usually high-salinity water to the surface layer. Upwelling is the process whereby the wind component paralleling the coast (northwesterly) drives the surface water offshore; these waters are replaced by deeper waters.

The North Pacific gyre is largely wind-driven. Seasonal variation of the winds is indicated by seasonal variation of the strength and location of atmospheric pressure cells. The currents respond to variations in wind. This system was qualitatively described for the California Current region by Reid, Roden, and Wyllie (1958). A strong northerly wind component in spring through fall strengthens the Current. In winter the northerly component weakens or reverses and a countercurrent develops along portions of the coast. The seasonal variation of the winds has a most noticeable effect on coastal upwelling. Upwelling is strongest when the north and northwest winds are strongest. This situation occurs off Baja California in April and May, off southern and central California in May and June, off northern California in June and July, and off Oregon in August (Reid, Roden, and Wyllie, 1958).

The largest and most complex changes in circulation occur in the coastal region. A countercurrent is present in late fall, winter, and early spring from central California to British Columbia (cf. Sverdrup, Johnson, and Fleming, 1942; Schwartzlose, 1963). A nearly permanent eddy is found among the Channel Islands off southern California. The eddy is weak or nil in March, April, and May (Schwartzlose, 1963; Reid, 1965). The countercurrent is usually continuous around Point Conception in November, December, and January. There is no countercurrent along northern Baja California, but major eddies do occur off southern Baja California.

An atlas of sea surface dynamic topography (referenced to 500 decibars) of the CalCOFI data is under preparation at the Scripps Institution of Oceanography (SIO). The contours and gradients define the direction and speed of the geostrophic currents.

The variations of circulation and upwelling have a pronounced effect on the seasonal variation of temperature and salinity. The seasonal variation of these characteristics was discussed at length by Reid, Roden, and Wyllie (1958). They gave representative curves of the variations for diverse areas constructed from monthly means of CalCOFI data, 1949–55, and other sources.

The following paragraphs are quoted from a review of the earlier work by Reid (1960, p. 81). In place of seasonal variation curves to which his paragraphs refer, the reader may examine similar figures of this paper (Figures 8, 10, 13 and 14).

". . . Far offshore the variation, which is principally the result of variation in radiation and exchange with the atmosphere, has a simple pattern with the greatest range in the highest latitude. Near the coast in the region of strong upwelling north of 34°N. the seasonal range is reduced and the cool period lengthened by upwelling. Between 28°N. and 34°N. the upwelling occurs earlier in the year, more nearly at the period of the offshore seasonal minimum, and increases the seasonal range. South of 28° N. it is the fall and winter countercurrent which accounts for the high range and delays the low until late spring.

"The seasonal variation in surface salinity . . . indicates that the direct effect of evaporation and precipitation is small, and, indeed, there is little coherence in the variation of the northern offshore stations. Inshore it is again the processes of upwelling in the north and the countercurrent in the south which dominate the seasonal variation. The effect of the spring and summer upwelling of deeper water to the surface in the north causes a wide range with the maximum value of salinity in summer. In the south the winter countercurrent brings highly saline water northward along the coast giving a maximum in winter. The two effects tend to cancel each other in the middle region between 28°N. and 34°N. latitude."

Recently, the seasonal variation of temperature and salinity at diverse levels in the Point Conception (Point Arguello) region has been examined in detail (Reid, 1965).

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[1] California Cooperative Oceanic Fisheries Investigations.

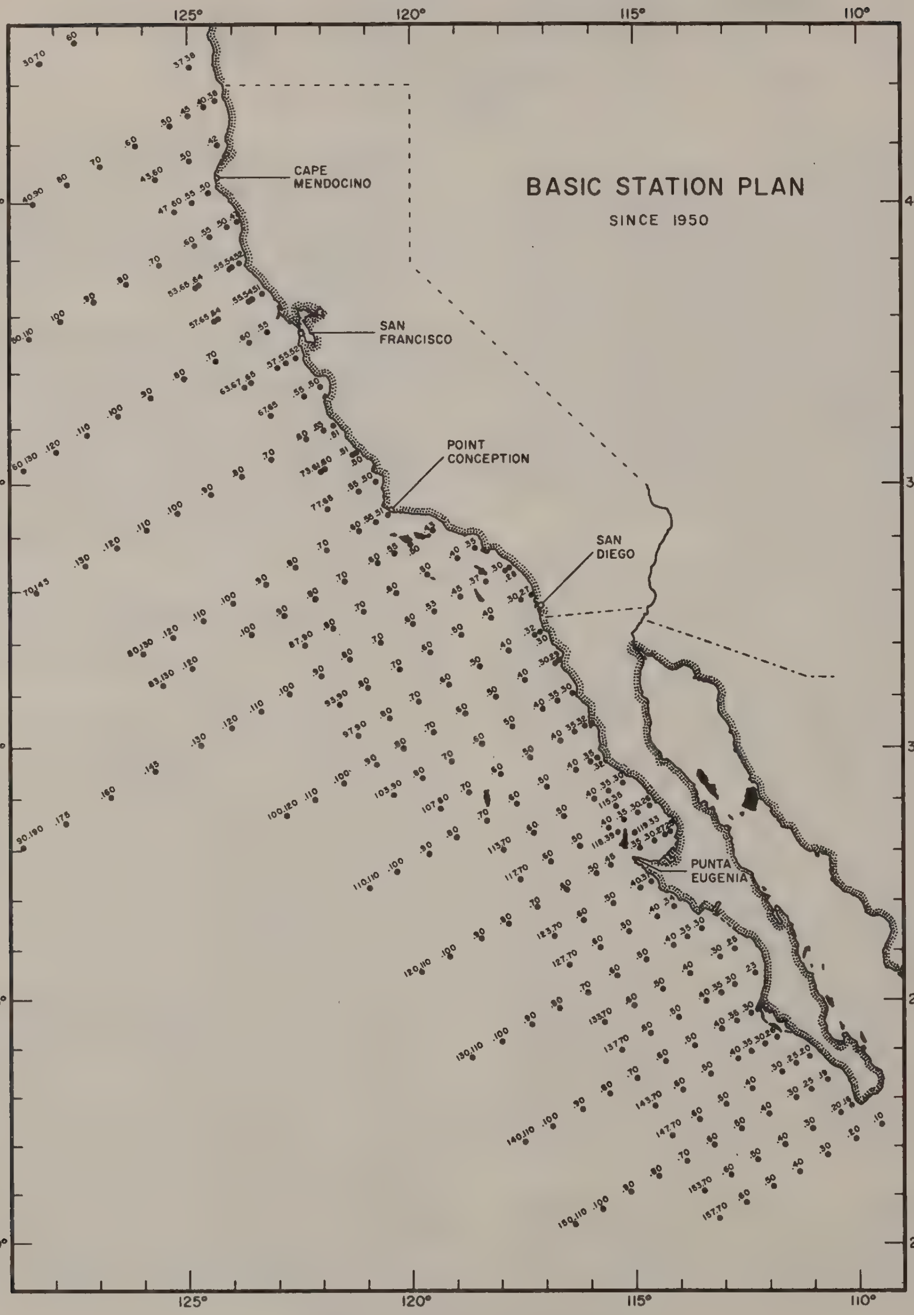
125°
120°
115°
110°
40°
35°
30°
25°
20°
BASIC STATION PLAN
SINCE 1950
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA

FIGURE 1. CalCOFI station plan since 1950.

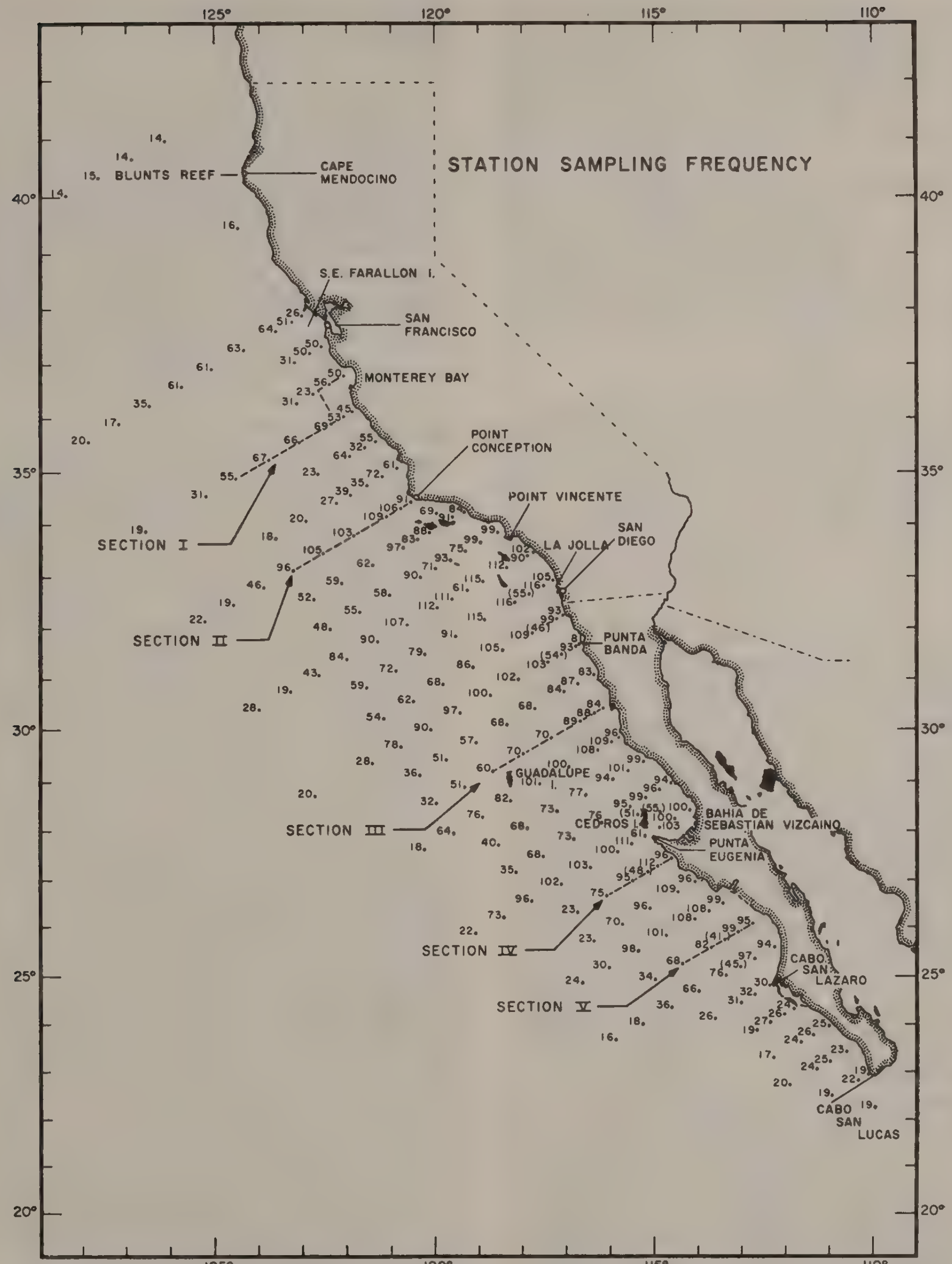
STATION SAMPLING FREQUENCY
125°
120°
115°
110°
40°
35°
30°
25°
20°
BLUNTS REEF
CAPE MENDOCINO
S.E. FARALLON I.
SAN FRANCISCO
MONTEREY BAY
POINT CONCEPTION
POINT VINCENTE
LA JOLLA
SAN DIEGO
PUNTA BANDA
GUADALUPE I.
CEDROS I.
BAHIA DE SEBASTIAN VIZCAINO
PUNTA EUGENIA
CABO SAN LAZARO
CABO SAN LUCAS
SECTION I
SECTION II
SECTION III
SECTION IV
SECTION V

FIGURE 2. Station positions of data records used in the regression analysis and their sampling frequency, 1950—62. Sections refer to Figure 14.

The papers cited have described the major features of the variations in temperature and salinity in the California Current region. The present study employs a totally different method of analysis which substantiates the previous findings. Detail is provided in some areas and for some months that has not previously been available. Almost all of the statistical treatment is new.

California Cooperative Oceanic Fisheries Investigations Atlas No. 1 (1963) contains distributions charts of 10-meter temperature and salinity for each CalCOFI cruise, 1949–59. The atlas also presents charts drawn from 10-year monthly means of temperature and salinity. Near the end of this paper a brief comparison is made between the mean distribution charts of the atlas and those derived from the present analysis.

THE DATA

The CalCOFI data through 1959 are published in the series, Oceanic Observations of the Pacific. Data for more recent cruises are available in the data report series (unpublished) of the University of California Scripps Institution of Oceanography.

Records for 222 stations were selected for analysis from the CalCOFI 10-meter data for 1950–62 according to criteria of occupancy and location (Figure 2). Thirty percent of the stations were occupied 14 to 50 times, and the remainder 51 to 119 times. The stations with the lesser frequency of sampling are found at the seaward extreme of the station pattern, off Cabo San Lazaro and south, and scattered among the stations north of Point Conception. These station records were used to extrapolate charting of the distributions beyond the better sampled areas. The observations are not evenly distributed throughout the year but occur more frequently in April–July, and less frequently in September, November, and December. Figure 13 shows time plots of data records with all years folded into one 12-month period. (An explanation of Figure 13 is given under STATION REGRESSION CURVES.) Only one observation per month was used; when duplicate observations were made, usually the one nearest mid-month was used.

In addition to the CalCOFI data, portions of records from five shore stations (surface only) were analyzed:

	Temperature	*Salinity*
Blunts Reef	1955–62	1957–62
S.E. Farallon Island	1955–62	1957–62
La Jolla	1950–62	1956–62[2]
Guadalupe Island	1956–60	——
Cedros Island	1957–62	——

Observations were made daily. The records were collected by the U.S. Coast and Geodetic Survey and Scripps Institution of Oceanography (unpublished). For this analysis, monthly averages (daily observations averaged for each month of each year) were entered as initial data. Thus, there is one value per month comparable in number to the CalCOFI sampling program, but with some high frequency variation filtered out.

CHOICE OF THE 10-METER LEVEL

Hydrographic casts were made during about 80 percent of the station occupations; the remaining 20 percent were ''net-haul'' stations, where work consisted of biological sampling and a 10-meter temperature and salinity measurement. The 10-meter level was chosen to represent the upper mixed layer in lieu of a surface sample to avoid such transient conditions as might be caused by rain or river runoff and by diurnal heating and cooling. In some places a shallow summer thermocline may develop. When this thermocline is shoaler than 10 meters it is readily subject to wind stirring; hence, its existence is usually brief. These arguments do not obtain in the vicinity of Cabo San Lucas[3] where oceanic fronts and other complex features persist (Griffiths, 1965).

ANALYSIS

An expression of the mean seasonal variation of a characteristic may be obtained from a digital record by Fourier polynomials, a method of harmonic analysis. Because the time intervals between data measurements are irregular, standard textbook formulas derived for processes sampled at equally-spaced intervals are unsuitable and hence an approach from basic concepts is necessary. A detailed description of each data record by harmonic analysis is not necessary; the only harmonics needed are those which contribute significantly to the description of the seasonal variation. This consideration leads to a different but totally equivalent approach which has an added advantage. The mean seasonal variation may be obtained by least squares regression of the data (considering each station record as a time series) to annually periodic sinusoids. Van Vliet and Anderson[4] analysed sea surface temperature records for seasonal variation by fitting annual and semiannual harmonics to the observed data by regression analysis. Their analyses were performed on long records of daily temperature observations at four shore stations and two weathership stations. Least squares regression analyses for curve fitting is identical to the more common application of estimating linear relationships. The added advantage of this method is seen in the statistical approach; it is a natural adjunct of regression analysis to compute measures of dispersion, correlation coefficients, and significance parameters. Though less natural, such computations can be made with truncated Fourier polynomials.

Natural events driven by insolation tend to vary with an annual cycle that may be roughly described by a sinusoid. However, because the effect of insolation is often indirect, the rough approximation provided by the annual sinusoid can usually be refined by including the semiannual harmonic.[5] The frequent 3- and 4-month gaps in the data records and the brevity of the records preclude any significant results from the third harmonic.

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[2] Validity of salinity observations for 1944–55 were questioned by Roden (1961); hence, these observations were not included in this analysis.

[3] Geographical locations are identified in Figure 2.

[4] Statistical analyses of sea surface temperature time series (unpublished manuscript). U.S. Navy Electronics Laboratory, San Diego, Calif.

The general form of the regression curve is:

$$y = A_1 \cos\theta + B_1 \sin\theta + A_2 \cos 2\theta + B_2 \sin 2\theta + C$$

where θ is the angular equivalent of the day of year in radians. In least squares regression the sum of the squares of the data anomalies from the regression curve,

$$\sum_i [y_i - (A_1 \cos\theta_i + B_1 \sin\theta_i + A_2 \cos 2\theta_i + B_2 \sin 2\theta_i + C)]^2,$$

is minimized with respect to each of the five coefficients where,

$$y_i = \text{data values indexed to } \theta_i$$

$$\theta_i = \frac{2\pi[(\text{month} - 1)\ 30 + \text{day}]}{360}$$

The resulting set of equations is solved simultaneously for the coefficients. The same coefficient formulas can be derived from the Fourier polynomial approach. When equal intervals are assumed (integral division of year) the formulas simplify to the standard textbook formulas for Fourier polynomial coefficients.

From the station regression curves were derived the long term mean (13-year), extreme values, and range. Statistics describing the data and the fit of the regression curve were computed by standard formulas. These statistics include standard deviation, standard error of estimate, coefficient of correlation, and the F-ratio test (null hypothesis: the mean provides as adequate a fit to the data as the regression curve). The coefficient of correlation refers to the correlation of the characteristic with time of year.

DISTRIBUTION OF THE 13-YEAR MEANS

The long term (13-year) mean of temperature (Figure 3) shows the influence of currents and upwelling. The mean temperature ranges from 12° C. near San Francisco to 24° C. near Cabo San Lucas. More than half the range (less than 18° C. to 24° C.) falls between Punta Eugenia and Cabo San Lucas, one-third of the total distance. The isotherms tend to parallel the coast along northern and central California with the colder water inshore, whereas the isotherms are nearly perpendicular to the shore along the southern part of Baja California. The colder inshore water along northern and central California is a mixture of cold waters from the North Pacific Current and cold waters upwelled along the coast. A second important upwelling region, indicated by a 16° C. isotherm, is near the coast immediately north of the United States-Mexican border and extending southward along northern Baja California. West of this upwelling region is a warm tongue-like feature extending into the island area off southern California.

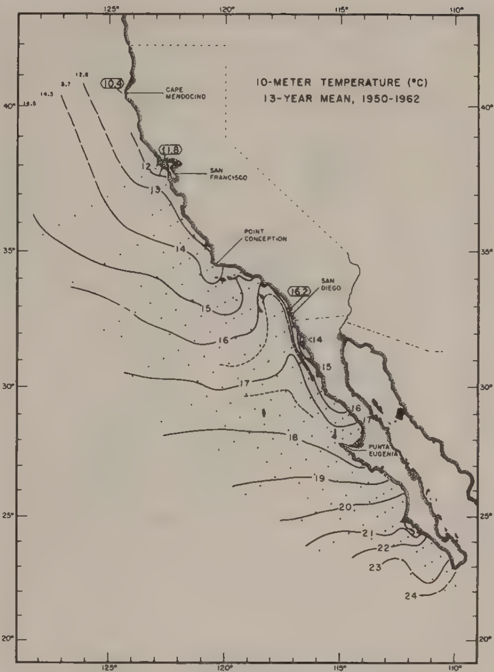

FIGURE 3. Ten-meter temperature (°C); 13-year mean, 1950–62. Interval: 1° C. In this and other figures thin, short-dashed lines show half intervals and thick, long dashes show continuation of standard-interval isopleths into regions of infrequent sampling. Boxed values refer to shore stations.

The long term mean salinity (Figure 4) ranges from less than 33.0‰ near Cape Mendocino to greater than 34.6‰ near Cape San Lucas. More than half this range is along southern Baja California. The largest gradients are in the southernmost portion of the CalCOFI area and in the upwelling region north of Point Conception. A low-salinity tongue, characteristic of the California Current, lies approximately 240 miles from and parallel to the northern California coast. The displacement of the low-salinity tongue farther offshore from the low-temperature tongue is evidently the consequence of the mixing of upwelled water, characteristically cold with high salinity, and California Current water, characteristically cold with low salinity. Along southern California and northern Baja California is a body of water with a nearly uniform mean salinity, 33.55‰ ± 0.05‰ and a small standard deviation, approximately ± 0.15‰. This area shows a complex distribution of mean temperature.

Reid, Schwartzlose, and Brown (1963) described a shoreward movement of water near latitude 31° N. to 32° N. Features in the 33.4‰ and 33.5‰ isohalines probably relate to this flow, as perhaps does the

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[5] Van Vliet and Anderson performed an autocorrelation analysis on the long records (7–40 years) of daily temperature observations and showed the semiannual harmonic contains a significant portion of the energy of seasonal variation in four of their six stations.

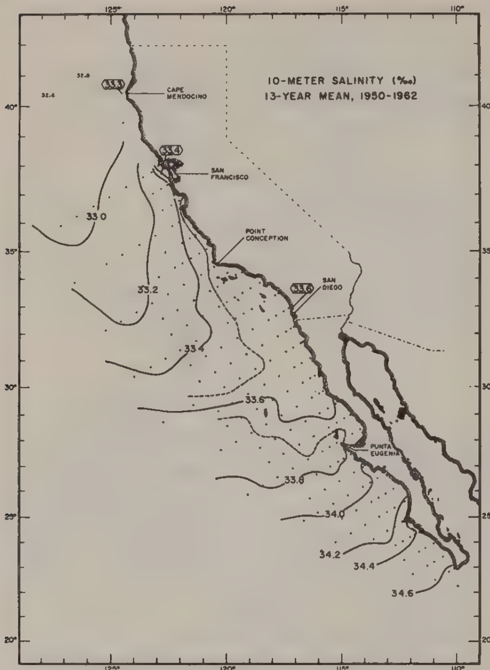
10-METER SALINITY (‰)
13-YEAR MEAN, 1950-1962
125°
120°
115°
110°
40°
35°
30°
25°
20°
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
32.6
32.6
33.3
33.4
33.0
33.6
33.2
33.4
33.6
33.8
34.0
34.2
34.4
34.6

FIGURE 4. Ten-meter salinity (‰); 13-year mean, 1950–62. Interval: 0.2‰.

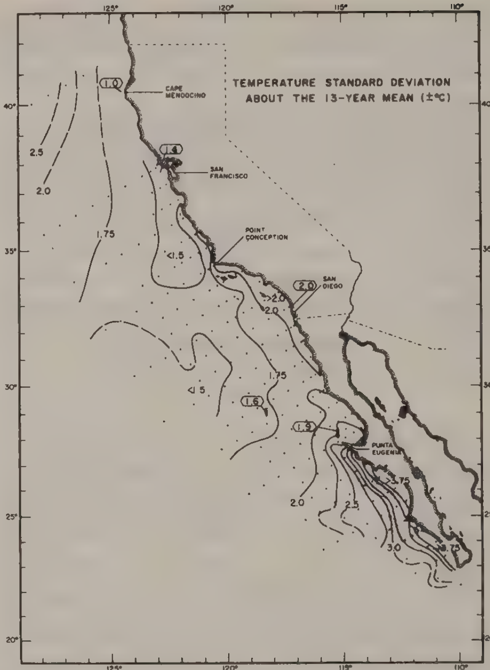
TEMPERATURE STANDARD DEVIATION
ABOUT THE 13-YEAR MEAN (±°C)
125°
120°
115°
110°
40°
35°
30°
25°
20°
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
1.0
1.4
2.5
2.0
1.75
<1.5
2.0
>2.0
2.0
1.75
<1.5
1.6
1.5
2.0
2.5
3.75
3.0
3.75

FIGURE 5. Standard deviation of temperature about the 13-year mean (± ° C.). Interval: 0.25° C.

slightly larger salinity gradient northwest of Guadalupe Island. The limited coverage of the CalCOFI pattern does not show the southward and southwestward continuation of the low-salinity tongue as shown by mean-salinity charts of the North Pacific Ocean (see, for example, Schott, 1935; Morskoi Atlas, 1950; or Norpac Atlas, 1960).

The results of analyses at shore stations are shown as boxed numbers on these and other distribution charts. The mean temperatures at the Guadalupe Island and Cedros Island Stations are 0.5° C. greater than at the adjacent stations. In both cases the records covered only half of the 13-year period. When neighboring CalCOFI stations were analyzed with equally truncated records no differences could be found in the means. Thus, temperature regression values for the two island stations are misleading and are not given.

STANDARD DEVIATION ABOUT THE MEAN

The distributions of standard deviation about the 13-year means appear in Figures 5 and 6. This measure of dispersion combines the seasonal and nonseasonal influences.

The chart of standard deviations for temperature shows a band of small dispersion, less than 1.75° C., extending across the CalCOFI region in a meridional orientation. One area of minimum (< 1.5° C.) is in the coastal upwelling region along central California. Another such area of minimum at the seaward extent of the coverage may be continuous with the zone of small temperature range in the sub-tropics (Thorade, 1909; Schott, 1935; Reid, 1962). Off northern California the standard deviation increases. A relative maximum (> 2.0° C.) occurs along the southern California-Baja California coast. There is a coastal high south of Punta Eugenia having values greater than 3.75° C.

The chart of standard deviations for salinity shows a coastal maximum (> 0.3‰) in the vicinity of San Francisco Bay, and a decrease seaward and southward (to < 0.15‰). The seaward minimum in standard deviation connects with the coastal minimum of the mid-CalCOFI region within the 0.175‰ contour. The body of water with nearly uniform salinity of 33.55‰ off southern California has a very small standard deviation. A maximum occurs near Guadalupe Island which is in a location immediately south of a large salinity gradient to be seen in the distribution of mean salinity. The area of greatest standard deviation (0.35‰) is centered 70 miles offshore from southern Baja California.

The distribution of standard deviations for salinity has a general relation with the gradient of mean

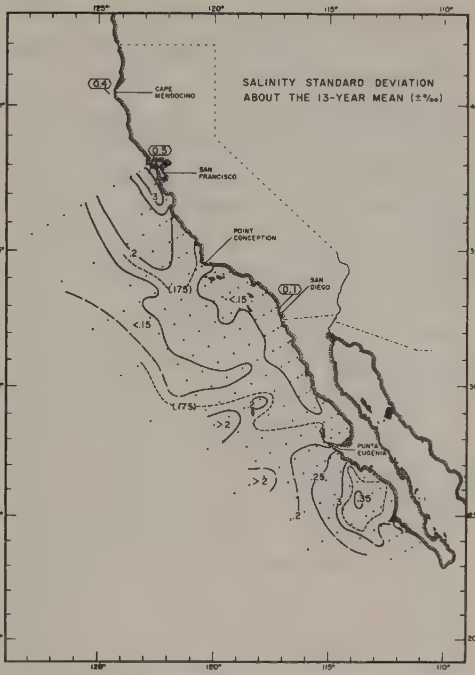
SALINITY STANDARD DEVIATION
ABOUT THE 13-YEAR MEAN (±‰)
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
0.4
0.5
0.1
.3
.2
(.175)
<.15
<.15
(.175)
>.2
>.2
.25
.3
.35
.2
125°
120°
115°
110°
40°
35°
30°
25°
20°

FIGURE 6. Standard deviation of salinity about the 13-year mean (±‰). Interval: 0.05‰.

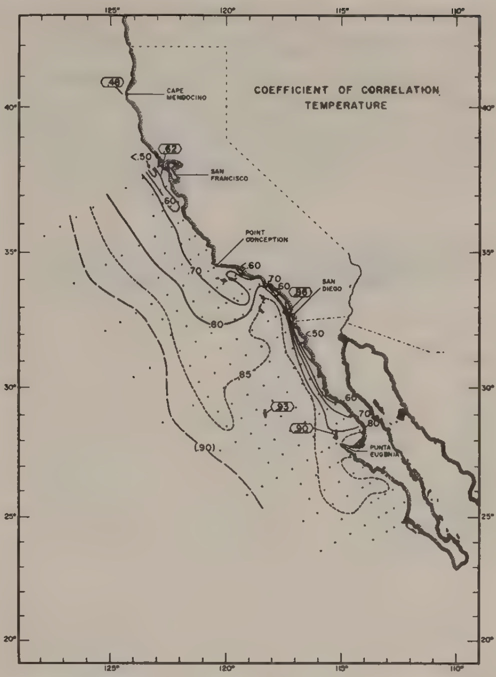
COEFFICIENT OF CORRELATION
TEMPERATURE
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
.48
.62
<.50
.60
.70
<.60
.70
.60
.88
.80
<.50
.85
.93
.90
(.90)
.60
.70
.80
125°
120°
115°
110°
40°
35°
30°
25°
20°

FIGURE 7. Coefficient of correlation for temperature. Interval: 0.1.

distribution. Areas of large gradient coincide with areas of large dispersion, and areas of small gradient with areas of small dispersion. This circumstance probably results from a large ratio of nonseasonal (random) to seasonal variation in the salinity record. The increase in standard deviation near the western edge of the CalCOFI region is not well established but it corresponds to relatively large salinity gradients seen in charts for the North Pacific Ocean.

COEFFICIENT OF CORRELATION AND MEAN RANGE: TEMPERATURE

The coefficients of correlation for temperature and salinity are measures of the degree of relation between the characteristics and time of year.[6]

The correlation of temperature with time of year (Figure 7) has a coefficient greater than 0.80 over the greater portion of the CalCOFI region. The coefficient is greater than 0.85 along the western extent and in the southern half including the coastal region along southern Baja California. Coefficients are smaller in the upwelling regions—in a broad band along central California and in a narrow band from Point Vincente to Bahia de Sebastian Vizcaino. Small coefficients are caused either by large total variance, consequent on the sporadic nature of upwelling, or by small explained variance that results when effects of upwelling are out of phase with the solar heating-cooling cycle dominant elsewhere. A mixture of these effects is probable.

The F-ratio test[7] was applied to the regression of the annual harmonic only.[8] Where the null hypothesis is rejected at the 2.5 percent significance level the seasonal variation may be considered significant. The seasonal variation of temperature is everywhere significant.

An additional test, attributed to Stumph by Conrad and Pollak (1950), was applied to 12 representative stations. The probability p that an amplitude A might have been obtained by harmonic analysis of a particular set of random numbers is given by:

$$p = \exp \frac{-A^2}{n^{1/2} \sum_{i=1}^{n} a^2{}_i}$$

---

[6] $R = \left(\frac{\text{variance explained by regression curve}}{\text{total variance}}\right)^{1/2}$ where R is the coefficient of correlation.

[7] $F = \left(\frac{\text{explained variance}}{\text{unexplained variance}}\right)$ weighted by degrees of freedom. The degrees of freedom are determined by the number of variables in the regression equation and the sampling frequency.

[8] Van Vliet and Anderson found by the F-ratio test that the semiannual harmonic significantly increases the explained variance in five of their six stations. Application of this test to the semiannual harmonics of the CalCOFI records is marginal in value because the number of data in each record is small.

where *ai* is the amplitude computed from the *ith* cycle of the period concerned and *n* is the number of intervals of this period in the series. At all stations tested the probability computed with the annual harmonic of temperature is inconsequential (Table 1).

The distribution of temperature range, maximum of regression curve less minimum (Figure 8), closely reflects the distribution of standard deviation. The major exception is in the region of low correlation along the coast of southern California-northern Baja California. Here the standard deviation increases to the coast, whereas the seasonal range reaches a maximum 20 to 40 miles offshore.

TABLE 1

PROBABILITY THAT AN AMPLITUDE (ANNUAL HARMONIC) AS GREAT AS THAT CALCULATED MIGHT HAVE BEEN OBTAINED BY HARMONIC ANALYSIS OF PARTICULAR SET OF RANDOM NUMBERS

Station	Temperature	Salinity
60.60	0.01	0.17
60.80	0.01	0.84
73.60	2×10^{-8}	0.39
80.51	1×10^{-8}	3×10^{-3}
80.55	2×10^{-4}	0.02
80.70	3×10^{-5}	7×10^{-4}
80.90	1×10^{-4}	0.22
90.37	7×10^{-6}	4×10^{-4}
90.70	3×10^{-6}	0.03
107.32	2×10^{-8}	5×10^{-3}
107.35	8×10^{-5}	0.88
107.50	4×10^{-6}	2×10^{-4}

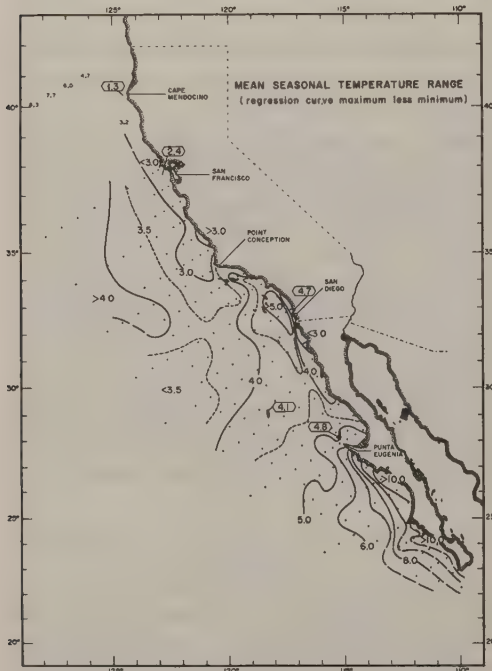

FIGURE 8. Mean seasonal temperature range which is defined as the regression curve maximum less the minimum. Interval: 1° C.

Temperature range is less than 3.0 °C. in the northern California upwelling region. The band of small range is defined by the 3.5° C. isotherms, and has flanking areas greater than 4.0° C. The isolated area with range greater than 5.0° C. off San Diego coincides with the warm tongue seen in the mean distribution. Temperature range exceeds 5.0 °C. in Bahia de Sebastian Vizcaino and south of Punta Eugenia, increasing to greater than 10.0 °C. along the coast of southern Baja California.

The chart of temperature range is grossly similar to range charts of the North Pacific Ocean (e.g. Reid, 1962). Considerable detail has been added by the present analysis. Robinson (1957) prepared a chart of surface-temperature range for the northeastern Pacific Ocean from a comprehensive study of bathythermograph records (and of some serial hydrographic data). Her chart (her Figure 44) overlaps the present coverage north of 35° N. latitude and shows the band of small range displaced offshore at the latitude of San Francisco. Her values are generally greater by 1.5° C. to 2.0 °C. Closer examination has revealed that most of the differences between the range charts are caused by differences in the determination of the seasonal temperature maxima. During the period of heat gain in the region where the coverage of the charts overlap the temperature of the surface layer may occasionally exceed that at 10 meters by more than 1° C. This difference may result from warming of newly upwelled water or warming of water with shallow density stratification caused by river and bay effluent.

Wyrtki (1964) prepared a chart of surface-temperature range for the eastern Pacific Ocean, 30° N. to 40° S. His chart is similar except in a narrow band along southern Baja California. In this region he did not find the range to exceed 7° C. The present analysis finds lower temperatures at the temperature minimum.

COEFFICIENT OF CORRELATION AND MEAN RANGE: SALINITY

The correlation coefficient for salinity (Figure 9) ranges from nominally zero to slightly greater than 0.70. There is a series of lobes having coefficients greater than 0.40. Only off southern Baja California are there any values greater than 0.60. The generally low values indicate that the nonseasonal variations dominate much of the salinity record.

The shaded areas show where the null hypothesis of the *F*-ratio is rejected at the 2.5-percent significance level. These areas of significant seasonal variation usually coincide with the areas having correlation coefficients greater than 0.40. The exception to this observation occurs north of 34° N. latitude where the sampling was less frequent. The probability com-

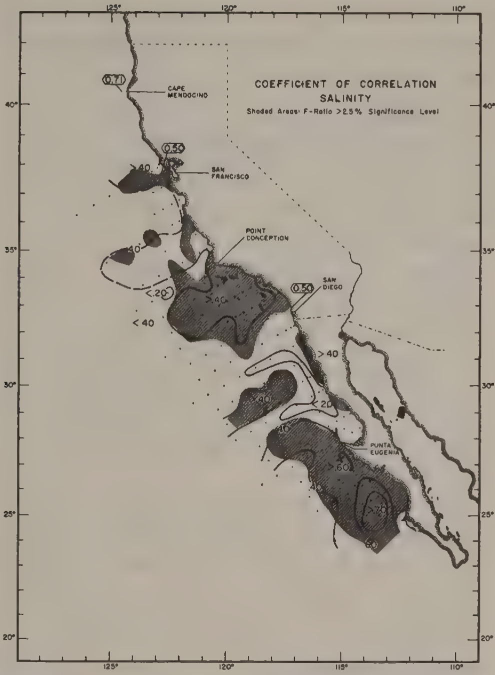
COEFFICIENT OF CORRELATION
SALINITY
Shaded Areas: F-Ratio >2.5% Significance Level
0.71
CAPE MENDOCINO
0.50
>40
SAN FRANCISCO
40
POINT CONCEPTION
<.20
>.40
<40
0.50
SAN DIEGO
>40
40
<20
40
PUNTA EUGENIA
>.60
40
>.70
60
125°
120°
115°
110°
40°
35°
30°
25°
20°

FIGURE 9. Coefficient of correlation for salinity. Interval: 0.2. Within the shaded areas the *F*-ratio is greater than the 2.5 percent significance level.

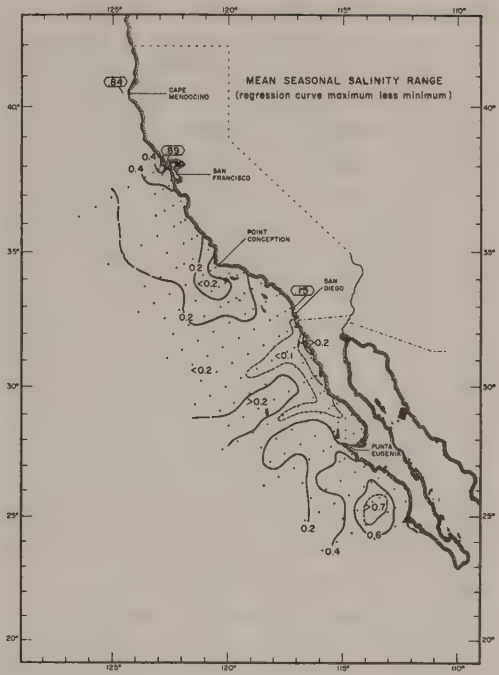
MEAN SEASONAL SALINITY RANGE
(regression curve maximum less minimum)
.84
CAPE MENDOCINO
.89
0.4
0.4
SAN FRANCISCO
POINT CONCEPTION
0.2
<0.2
0.2
.75
SAN DIEGO
>0.2
<0.1
<0.2
>0.2
PUNTA EUGENIA
>0.7
0.2
0.6
0.4
125°
120°
115°
110°
40°
35°
30°
25°
20°

FIGURE 10. Mean seasonal salinity range which is defined as the regression curve maximum less the minimum. Interval: 0.2‰.

puted by Stumph's test for the salinity harmonics show large differences (Table 1). The same conclusions are drawn from this test as from the coefficient of correlation and *F*-ratio; the seasonal variation of salinity is real but small in comparison to nonseasonal fluctuations. Some areas need more frequent sampling to demonstrate a signficant seasonal trend.

The distribution of the range of mean salinity (maximum of regression curve less minimum, Figure 10), reflects that of correlation coefficient and standard deviation, especially the former. Three major regions have a range greater than 0.2‰; two of them have ranges greater than 0.4‰. The maximum range contour, 0.7‰, is centered 100 miles offshore from southern Baja California. This maximum contains most of the stations which have a range equivalent to two standard deviations or more. The other region of range greater than 0.4‰ is found near San Francisco Bay. The shore station at S.E. Farallon Island which includes data for only 5 years, 1957–62, has a range of 0.9‰. This station exhibits an abrupt minimum in March coinciding with the peak discharges of the Sacramento and San Joaquin Rivers. The nearby CalCOFI stations were infrequently sampled in this month and thus may have produced an abbreviated range. On the other hand, the range at the shore station was increased because samples were taken at the sea surface.

The range along northern Baja California is small; only one upwelling station (100.29) has a range greater than 0.2‰. Twenty miles offshore is a band of especially small salinity range. This band also displays an extremely small coefficient of correlation.

SHORE STATIONS

Some of the results of the analyses of data from shore stations are similar to those for local hydrographic stations. Results for Blunt's Reef station appear to be consistent with an extrapolation of more southerly results. The temperature analysis at S.E. Farallon Island is identical to that of neighboring CalCOFI stations. The salinity analysis for the same station (only 5 years of record) gave greater deviation, range, and correlation. The other shore stations have slightly smaller deviations and greater correlation coefficients than neighboring CalCOFI stations. These results may be caused by the filtering process of using monthly averages as shore station input data. The ranges did not differ among these stations.

REGRESSION CURVE EXTREMES

The extremes of the station regression curves and their months of occurrence are shown in contoured charts (Figures 11 and 12). The seasonal temperature minimum occurs in March over most of the oceans in the northern hemisphere temperate zone. The seasonal maximum occurs in September. The timing of the variation is altered near the coast in the CalCOFI area. In regions of upwelling and regions influenced by upwelled waters the minimum occurs late, usually in April and May. Off southern Baja California the late temperature minimum extends beyond the offshore influence of the coastal upwelling. In this latter region the anomaly in phasing of the temperature variation appears to result from seasonal variation in advection. A region off southern California has an early temperature minimum. The scale and location of this region offer evidence that the phase lead is caused by the pattern of the local currents. The seasonal temperature maximum occurs earliest (August) in a limited area off southern California. The coastal upwelling region of central California experiences its maximum temperature as late as the end of November. The maximum is slightly late at a few prominent upwelling stations along the Baja California coast.

Because the seasonal variation of salinity is considerably less regular than that of the temperature (at some stations the variation is not significant) the distribution of extreme dates is not as definitive as those for temperature. A general pattern is evident, however. Where the seasonal variation is significant seaward of the upwelling regions the salinity minimum is in spring and the maximum in fall. This timing agrees with the seasonal variation of advection and its probable effect on the distribution of mean salinity. In the upwelling regions along central California the maximum salinity is in summer, shortly after the minimum temperature is attained. The minimum salinity usually occurs in winter. The salinity extreme in the upwelling region along northern Baja California occurs earlier than for the region farther north. The salinity maximum along southern Baja California occurs in fall along with the countercurrent.

STATION REGRESSION CURVES

The complete data records and station regression curves for five representative stations are plotted in Figure 13. The dashed lines are drawn at plus and minus one standard error of estimate of the characteristic from the regression curve.

Station 70.52 is in the upwelling region, 6 miles from the shore and immediately south of Monterey Bay.[9] At this station the correlation coefficients are low and standard errors of estimate are large. Data are scarce for the winter months. The dispersion of the salinity values is particularly large at the beginning of the upwelling season, April and May. The upwelling season along northern and central California is characterized by the low temperatures in spring and summer with accompanying high salinities. Sometimes the temperature and salinity anomalies show an inverse relation. In particular, the highest and lowest salinities for April have as their corresponding temperature observations the lowest and highest April temperatures, respectively.

Station 70.70 is 80 miles farther offshore. The temperature variation has a greater correlation coefficient, and a lesser standard error of estimate than at the nearshore station. The salinity record shows a poorer correlation and greater standard error of estimate. The offshore salinity variation is very different; its minimum is in spring. The very large positive temperature anomaly and negative salinity anomaly were observed in June 1958. The observations of this anomalous water show that its extent was limited (CalCOFI Atlas No. 1).

These two stations show the large standard error of estimate relative to the moderate ranges in seasonal variation that typifies the surface water in the CalCOFI area north of the latitude of Point Conception. The regression analysis of salinity is of marginal significance. The *F*-ratio test indicates that the regression curves of these example stations provide a better estimate of the salinity than the mean, although the regression curves of some neighboring stations are not significant. Stumph's test (calculated for neighboring stations but not for these particular stations) indicates that the salinity variation within each year may differ considerably from the mean regression curve.

Nonsignificant results from a regression analysis may be a direct result of a low sampling frequency. The stations off central California have moderate to poor sampling frequency and an uneven distribution of data within each year.

The regression curve and record of temperature for station 93.50 and similarly of salinity for station 87.50 also appear in Figure 13. Both stations are off southern California. The standard errors of estimate of the regression curves are small. The range of the salinity curve is moderate, having the same value as the spread of one standard error of estimate above and below the curve. Thus the correlation is moderate. The salinity curve is similar to that for the upwelling station, 70.52. Station 87.50 is just north of San Nicolas Island and over the submarine ridge of which San Nicolas is a part. The depth at this station is 73 meters. The corresponding temperature curve is similar to that of station 93.50 but has a lesser range and poorer correlation, 3.2° C and 0.67, respectively.

The late temperature minimum shown in the curve for 93.50 also appears in a few neighboring stations, all of which are downstream of the cold upwelled water added to the California Current at Point Conception and north. The corresponding salinity curve

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[9] The data plotted for station 70.52 were actually obtained at three stations, 70.51, 70.52, and 70.53 with an interval of 4 miles between 70.52 and the others. With one exception no two stations were occupied during the same cruise. The short distance between the stations was considered to be of minor consequence as compared to the month-to-month changes of temperature and salinity in the locale of the stations. Therefore, the data were combined as if observed at one station. Data were similarly combined at several other coastal CalCOFI stations.

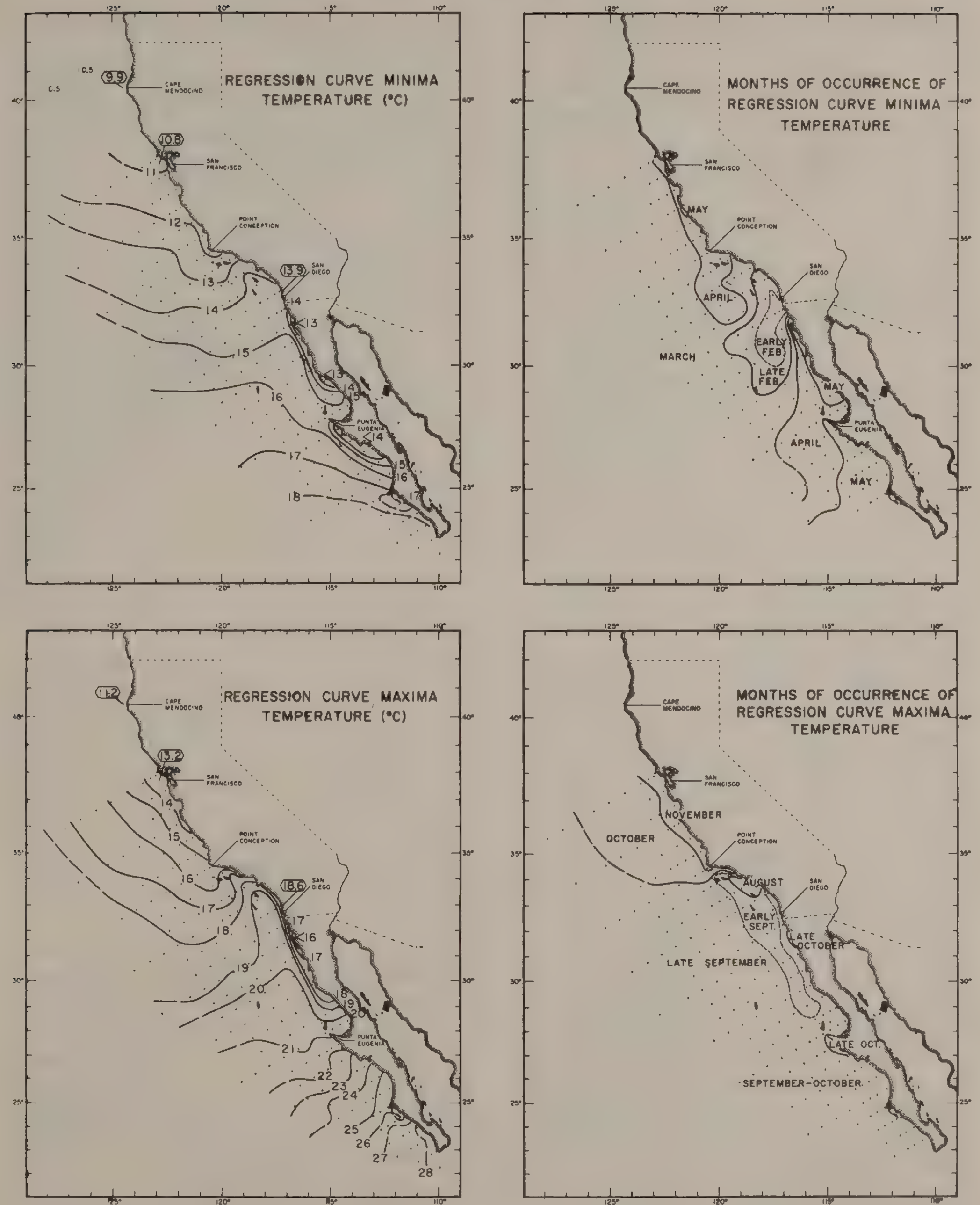
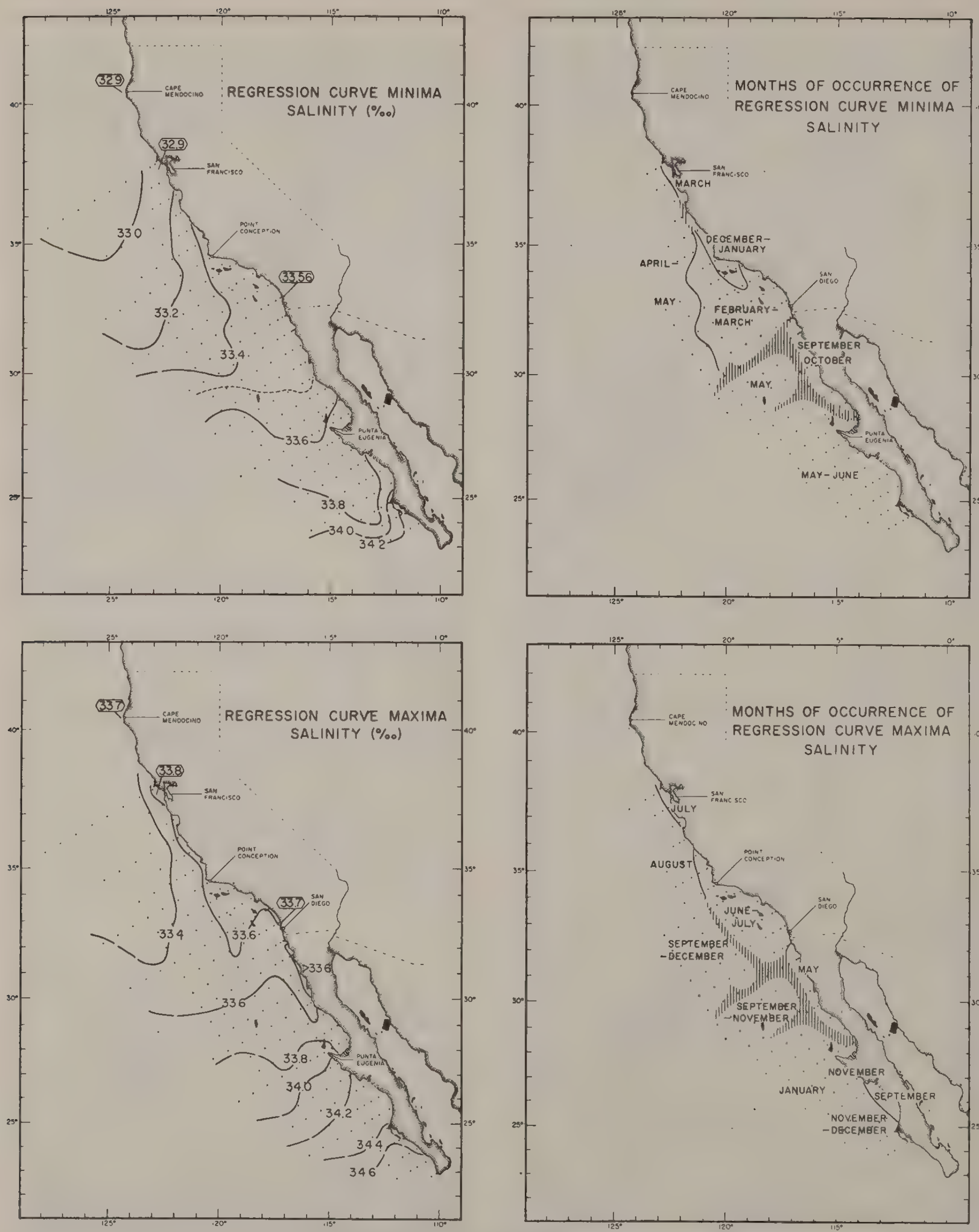

REGRESSION CURVE MINIMA TEMPERATURE (°C)
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
10.5
9.9
10.8
11
12
13
13.9
14
15
16
17
18
MONTHS OF OCCURRENCE OF REGRESSION CURVE MINIMA TEMPERATURE
MAY
APRIL
MARCH
EARLY FEB
LATE FEB
REGRESSION CURVE MAXIMA TEMPERATURE (°C)
11.2
13.2
18.6
19
20
21
22
23
24
25
26
27
28
MONTHS OF OCCURRENCE OF REGRESSION CURVE MAXIMA TEMPERATURE
NOVEMBER
OCTOBER
AUGUST
EARLY SEPT.
LATE OCTOBER
LATE SEPTEMBER
LATE OCT.
SEPTEMBER–OCTOBER
125°
120°
115°
110°
40°
35°
30°
25°

FIGURE 11. Extremes of temperature regression curves and corresponding months of occurrence.



REGRESSION CURVE MINIMA SALINITY (‰)

MONTHS OF OCCURRENCE OF REGRESSION CURVE MINIMA SALINITY

REGRESSION CURVE MAXIMA SALINITY (‰)

MONTHS OF OCCURRENCE OF REGRESSION CURVE MAXIMA SALINITY

125°
120°
115°
110°
40°
35°
30°
25°
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
32.9
32.9
33.0
33.56
33.2
33.4
33.6
33.8
34.0
34.2
MARCH
DECEMBER–JANUARY
APRIL–
MAY
FEBRUARY–MARCH
SEPTEMBER OCTOBER
MAY
MAY–JUNE
33.7
33.8
33.7
33.4
33.6
>33.6
33.6
33.8
34.0
34.2
34.4
34.6
JULY
AUGUST
JUNE–JULY
SEPTEMBER–DECEMBER
MAY
SEPTEMBER–NOVEMBER
NOVEMBER
JANUARY
SEPTEMBER
NOVEMBER–DECEMBER

FIGURE 12. Extremes of salinity regression curves and corresponding months of occurrence.

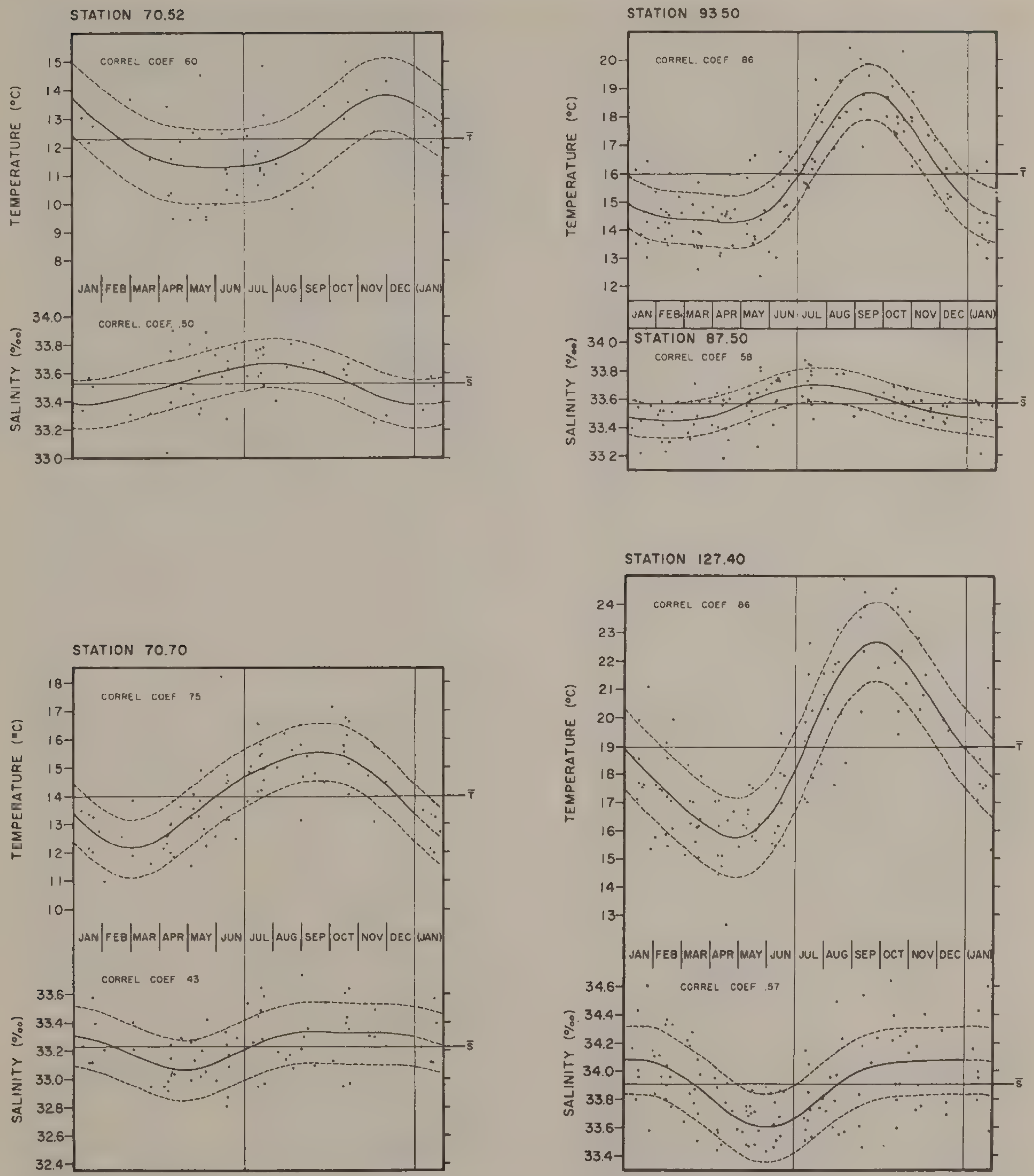


FIGURE 13. Station regression curves and observations. Station locations can be found with the aid of Figure 1. Horizontal lines are 13-year means. Dashed lines are drawn at plus and minus 1 standard error of estimate.

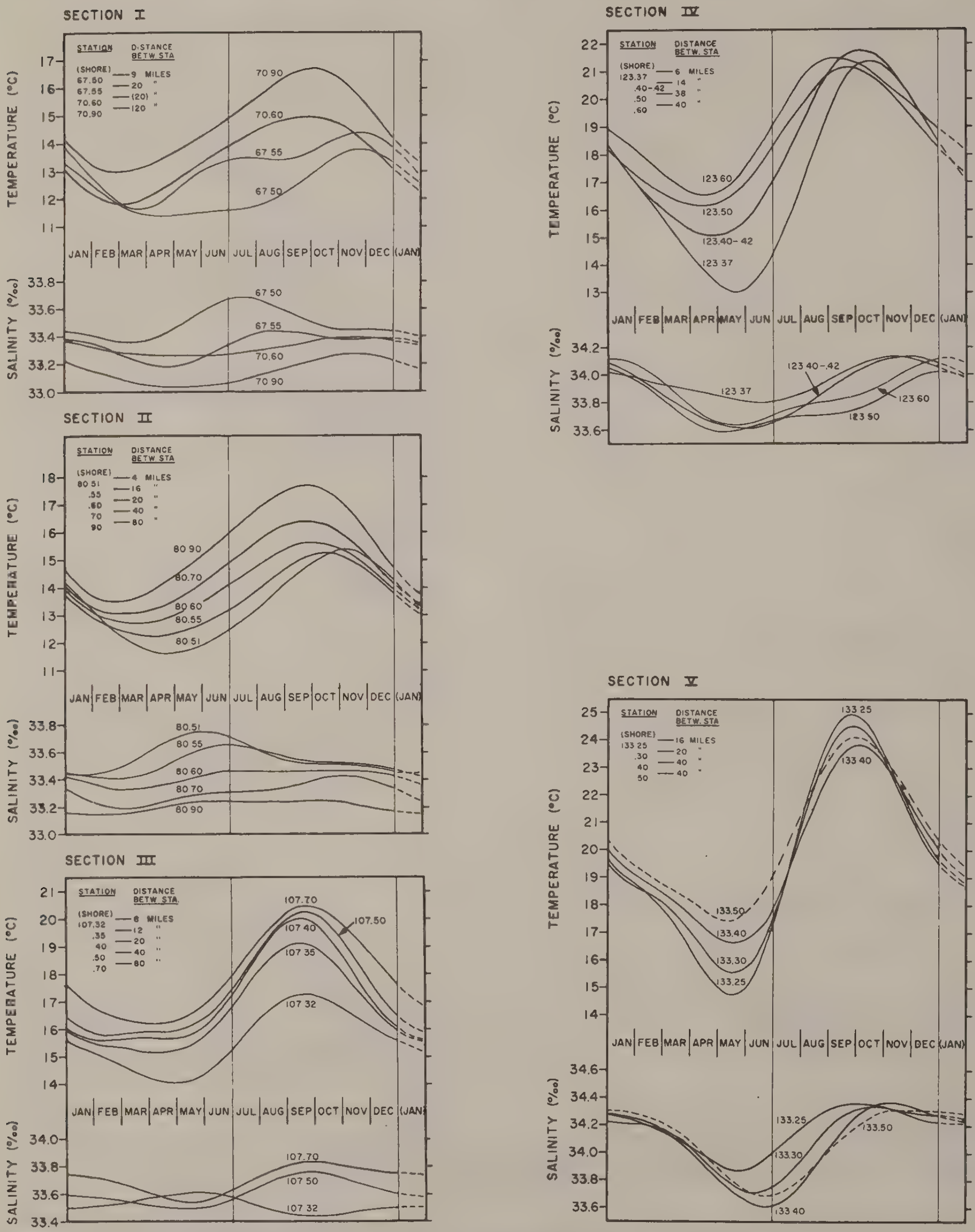


FIGURE 14. Station curves of seasonal variation of temperature and salinity grouped from lines perpendicular to the coast and labeled as sections. Sections locations are shown on Figure 2.

for 93.50 has a very small range and poor correlation, 0.17‰ and 0.33.

The temperature curve for station 127.40, off southern Baja California, has a 50-percent greater range than that for station 93.50, and a 50-percent greater standard error of estimate. These effects cancel to produce the identical correlation coefficient. The range of the salinity curve and its standard error of estimate are each greater by a factor of two than those for station 87.50; thus it also has the same correlation coefficient. At station 127.40 the seasonal temperature minimum is in late April and the seasonal salinity minimum in May. This aspect indicates an influence by some seasonal variation in circulation.

Station regression curves fall into regional patterns. Meaningful pattern variations occur perpendicular to the coast. Figure 14 gives station regression curves superimposed upon one another for easy visual comparison. For each graph, four or five stations were chosen that constituted a line section across the current and perpendicular to the coast. The locations of the line sections are shown as dashed lines in Figure 2. The jog in section I which includes stations from lines 67 and 70 was made to show typical station curves from stations that are well sampled. The distance between neighboring stations is given to provide the correct perspective of offshore temperature and salinity gradients. A time scale that is common to the temperature and salinity curves allows visual comparison of the variation of these characteristics.

As its temperature and salinity curves show, station 67.50 of section I is in an upwelling region. Station 67.55, 20 miles farther offshore, is similar to the offshore regime during the initial part of the upwelling season, but by midsummer the temperature curve responds to the effects of upwelling. The form of the corresponding salinity curve is also intermediate between those for the offshore and upwelling regimes.

Station 80.51, section II, near Point Conception does not maintain its low temperature as long as upwelling stations farther north. The slightly higher temperature at 80.51 than offshore in December and January may be caused by the winter countercurrent sometimes found along the coast.

The offshore temperature gradient along section III increases after the minimum temperature is reached and is largest at the time of the maximum temperature. Thus, the temperature gradient, but not the value of temperature, may indicate continued upwelling through September. Initial upwelling (station 107.32) brings high-salinity water to the surface. The salinity minimum follows the maximum by 4 or 5 months and coincides with the large temperature gradient. The salinity distribution charts for 10 meters (following text) for August through December reveal isolated low-salinity water in the upwelling region along the northern Baja California coast. This low-salinity water which replaces the isolated high-salinity water of May and June has its source in the salinity-minimum layer of the thermocline. The salinity minimum was described by Reid, Roden, and Wyllie (1958) and was the subject of a paper by Reid, Worrall, and Coughran (1964). These authors ascribed the minimum to freer horizontal mixing of the surface waters than of the thermocline water; the higher salinities of the west mix laterally into the surface water of the California Current more readily than into the thermocline layer. A study of data of CalCOFI hydrographic stations reveals that the salinity minimum which approximately corresponds to the 300 cl/ton thermosteric anomaly[10] surface extends to the coast in the latter half of the year. The higher salinity water upwelled in spring comes from a denser source. Thus, as the temperature gradients indicate, the upwelling may persist from spring through fall. Upwelling brings high-salinity water to the surface layers in spring and low-salinity water in fall. Though the offshore temperature gradient is maintained in this period the temperature goes from its seasonal minimum to its maximum.

Offshore, along section III, the salinity changes have phasing opposite to that of the nearshore regime in response to advection changes. In the intermediate region the opposing effects cancel and here no variation of salinity is found. This region has especially low correlation coefficient and range (Figures 9 and 10).

In surface distribution charts, station 123.37, section IV, appears to be the dominant upwelling station along a section of coast where the scope of upwelling is limited. The largest offshore temperature gradient occurs in late June, 2 months after the minimum temperature. Along station line 133, section V, the offshore gradient is largest at the time of the temperature minimum and an onshore gradient occurs at the maximum. Along both station lines the salinity minimum nearly coincides with the temperature minimum as in the offshore regions farther north. At this time an onshore salinity gradient is evident, perhaps produced by upwelling. Beginning in September, the four salinity curves of station line 123 fall into two groups, probably the result of a cyclonic eddy centered between stations 123.42 and 123.50 and the countercurrent.

DISTRIBUTIONS OF MONTHLY MEAN TEMPERATURE

Charts of mean temperature for each month were constructed from the curves of seasonal variation by digitizing the regression curves at midmonths (charts follow text). Smoothing of the contours was performed in the manner that gave greater emphasis to values at those stations which had relatively more frequent sampling (Figure 2). The stations offshore and south of Cabo San Lazaro were sampled infrequently during some seasons. In such situations, where the regression curve can only provide a tenuous interpolation, the values were excluded from the charts. Where the contours as drawn violate the given value, that value is shown in parentheses.

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[10] Montgomery and Wooster (1954). Approximately equivalent to the 24.97σt surface.

The seasonal variation of temperature off northern California can be characterized by noting the various positions of the 12° isotherm in the monthly charts. The broadest extent of water with temperatures less than 12 degrees occurs in March. Subsequent monthly charts show the development of a band of such cool water along the coast south to Point Conception. The 12-degree isotherm begins its retreat to the north in June and is not found in the last 3 months of the year. The maximum offshore temperature gradient from this cold upwelled water is in August.

The March temperature chart shows the tongue of warm water in the island area off southern California. This feature, which develops in prominence in subsequent months, occurs in the region of early (February) temperature minimum (Figure 11). It is produced from local differences in advection in conjunction with coastal upwelling (Reid, Roden, and Wyllie, 1958). The offshore waters are readily replenished with cold waters from the north whereas nearer shore the slower moving waters respond to the local heating. The coastal upwelling of deep cool waters causes the warmed nearshore waters to assume the tongue-like pattern. This feature appears in 10 of the monthly charts; the exceptions are January and February. Its greatest development comes in late spring and summer when the southern California eddy is reestablished.

The July and August charts both show an isolated warm region off San Diego. The separation of this region from the main body of water with the same temperature is significant and can be explained by the current flow. A northeasterly flow feeds water into the southern California eddy. Part of the northeasterly flow branches off to turn southeast along the coast of Baja California. The branching coincides with the center of the isolated warm region. At such a division the flow is sluggish. Along the northern Baja California coast the flow is relatively swifter and mixes with the upwelled water. This difference in rate of advection in conjunction with a net heat gain and the inclusion of upwelled waters produces the separation of warm waters. The isolated high-temperature region occurs in other months, though weakly, and would be revealed with a finer scale of contour interval.

In summer there is a 6° temperature difference between the warm waters off southern California, in the vicinity of Santa Catalina Island and the waters off Point Conception, approximately 120 miles distant. In winter the difference is less than 1°.

Upwelling along northern Baja California, as revealed by the temperature field, may occur throughout the year. Upwelling of cold waters is clearly characteristic of April through October; however, coastal temperatures remain less than offshore values throughout the winter. The temperature distribution for individual CalCOFI cruises (CalCOFI Atlas No. 1) support this conclusion as to mean conditions. Small pockets of cold water are found along this coast in many winters. Because there is usually no seasonal countercurrent along northern Baja California, as is found elsewhere, the mass distribution associated with geostrophic balance (for a southerly flow) provides the tendency for lower inshore temperatures at 10-meters throughout the year. Along this section of coast the lowest temperatures occur in April, May, and June, and the largest offshore gradient occurs in July, August, and September. The temperature values at one station (100.29) near Punta Banda require an additional isotherm in seven of the monthly charts.

The upwelling south of Punta Eugenia is centered about station 123.37. The minimum temperatures again are in April through June, but the largest temperature gradient is in June and July. Upwelling ceases before September and does not resume until April. During the upwelling season the isotherms are nearly parallel to the coastline. By September the isotherms have swept northward and are nearly perpendicular to the coastline. During this change considerable warming takes place. In addition to *in situ* heating, an influx of more southerly warmer waters is suggested by the configuration of the isotherms. This influx also appears in the mean salinity distributions discussed later.

The data from the few cruises that extended to the southern tip of Baja California in the upwelling season indicate that a pattern similar to that seen off Punta Eugenia may exist off Cabo San Lazaro. The coolest water is found at station 143.26.

Whereas the distribution of mean temperature in the upwelling regions appears as smooth isotherms, the distributions for individual cruises—especially those with very close station spacing—show that the cold water appears as pockets and tongues. It is probable that higher frequency sampling of a denser pattern of stations would reveal a complex but significant distribution of mean temperature having recurrent upwelling pockets associated with coastal configuration, shelf topography, and local variations in wind stress. That the mean characteristics of a few nearshore stations define large and significant gradients supports this idea.

DISTRIBUTIONS OF MONTHLY MEAN SALINITY

Low-salinity water enters the CalCOFI region from the northwest. On the basis of the limited sampling available water of salinity less than 33.0‰ appears to be in or near the CalCOFI region throughout the year. There is little apparent seasonal variation of salinity in the low-salinity water, < 33.4‰, with the exceptions of the southeastward projecting tongue of water defined by the 33.4‰ isohaline, and the coastal upwelling regions. The tongue of low-salinity water extends farther to the southwest in spring than in fall and, hence, its position correlates with the strength of the California Current. The coastal regime is complex and some difficulty results from the station spacing and sampling frequency. The station regression curves for stations near San Francisco Bay show marginal significance. The low-salinity effluent from the bay is greatest in the spring coincident with upwelling of high-salinity water north and south of the bay. A pattern of isohalines, broken at San Francisco Bay, is shown in charts for April through August. The pattern is simpler for the remainder of the year although the data for January, February, and March are not clear.

South of Monterey Bay water with salinity $> 33.4‰$ is always present in the mean. This salinity is greater than that found farther from the coast. The coastal high salinity is maintained by upwelling in the spring and summer and by the high salinity of the countercurrent (either directly by the advection or by vertical mixing with submerged countercurrent waters) in autumn and winter.

Upwelling regions have high-salinity water in spring and summer. Beginning in March and carrying through until July an isolated high-salinity region develops along the coast north and south of Point Conception and among the Channel Islands. In August through October the isolated high-salinity region is found only among the islands having successively smaller extent. The large temperature gradient (6° C. in 120 miles in June) occurs within this body of water. In part, the high salinities are formed by upwelling in the vicinity of Point Conception and the distribution is further influenced by the circuitous flow of the large eddy. The mass distribution associated with geostrophic balance requires that denser water, in this instance the higher salinity water, be found at shoaler depths to the left of the direction of flow (in the northern hemisphere). The spring increases in current flow amplifies this effect. The reestablishment of the large eddy in June centers the denser water in the island region and causes the mixed layer to be thin. In the Channel Island region, at depth, there is a greater percentage of water of southern origin than offshore (Sverdrup and Fleming, 1941). This water has a higher salinity at a given density than water of northern origin. All of these facts favor high salinities in the island region.

The seasonal variation of salinity off southern Baja California is markedly affected by advection. Starting in spring and developing into early summer the isohalines bend sharply towards the southeast. The lower salinities form a tongue-like distribution. The higher salinities along the coast must in part be maintained by upwelling. The northwestward projection of high salinity water near Punta Eugenia in September indicates an influx of more southerly water and corresponds to a cyclonic eddy sometimes found there in this season.

NEW CHARTS COMPARED TO PREVIOUS CHARTS

The mean (monthly) temperature and salinity charts of CalCOFI Atlas No. 1 were constructed from station averages with a base period of 1950–59. Station averages based on fewer than five observations (for each month) were not used. Consequently, the distributions for some months have large gaps. The distributions of properties in the Atlas No. 1 charts and these newer charts are closely similar. The larger differences are in the salinity charts and in the areas of limited sampling. No attempt is made to provide representative differences because in some areas small differences may mean a large displacement of an isopleth whereas in other areas the opposite is true. The change in base period has an uneven effect depending upon sampling frequency and its change. The addition of the 33.5‰ isohaline (half of the standard interval) in the newer charts adds important definition.

ACKNOWLEDGMENTS

I thank Joseph L. Reid, Jr., and Gunnar I. Roden for guidance and many helpful suggestions. Marvin Cline did the computer programming.

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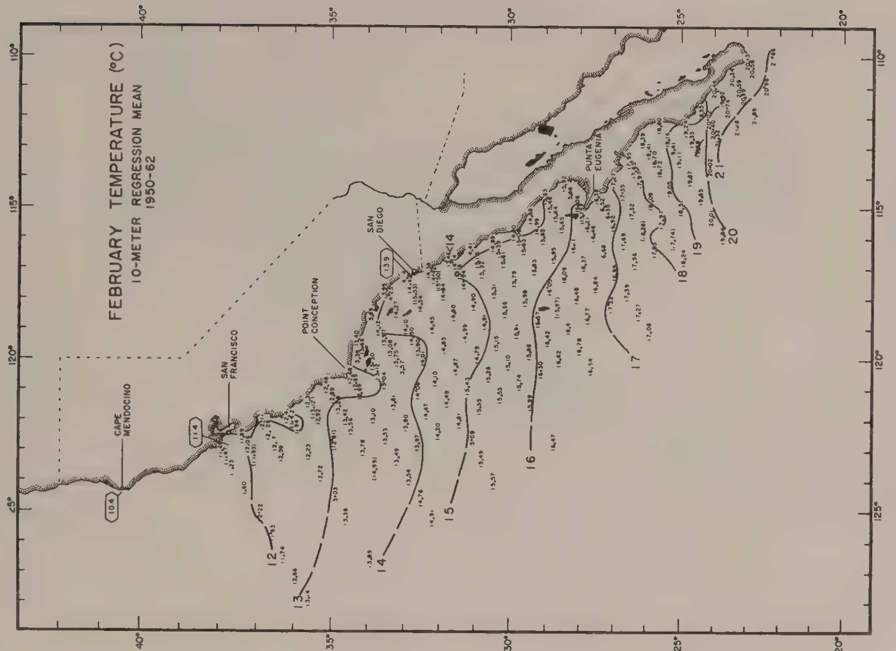
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1950-62
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POINT CONCEPTION
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PUNTA EUGENIA
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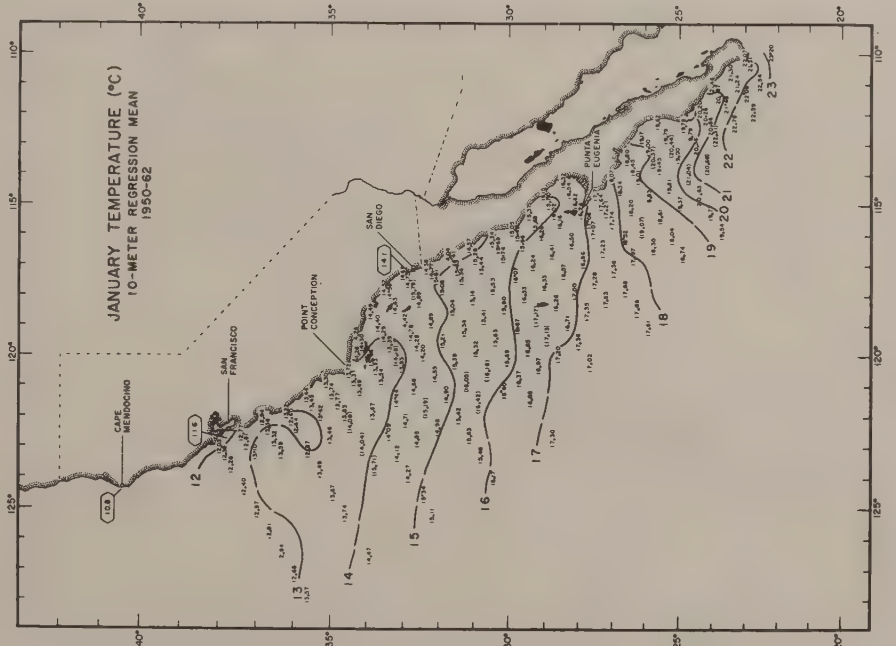
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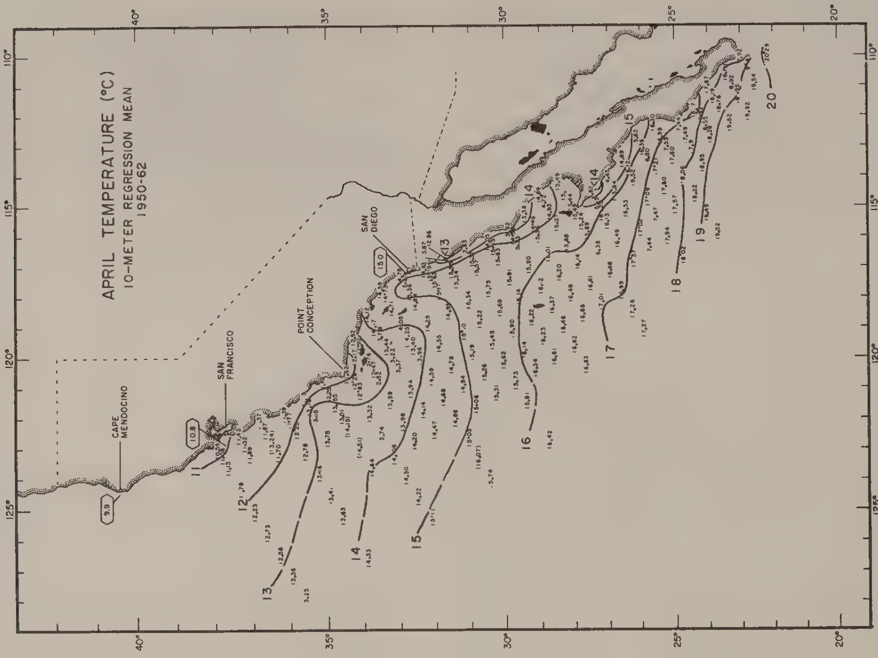
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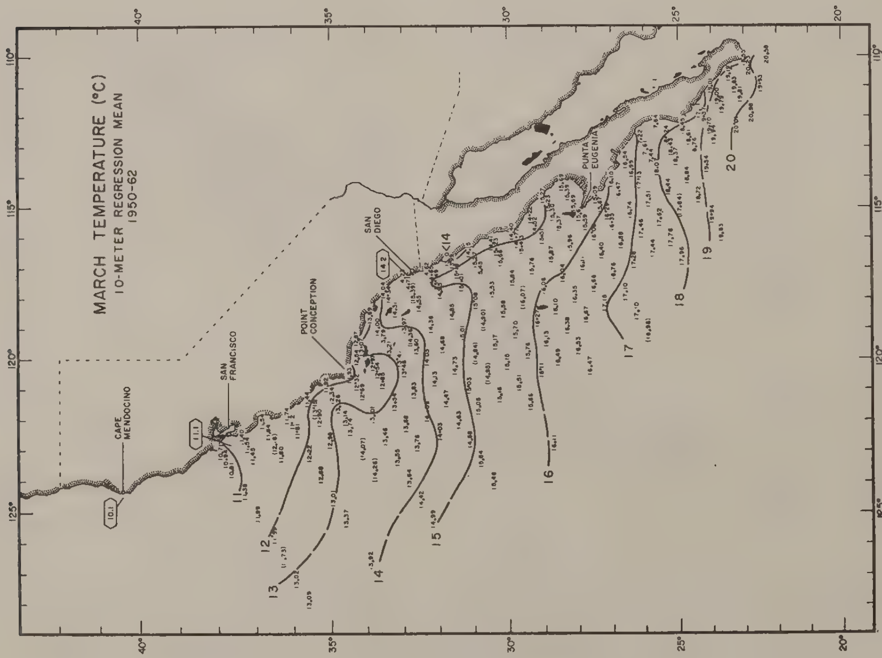
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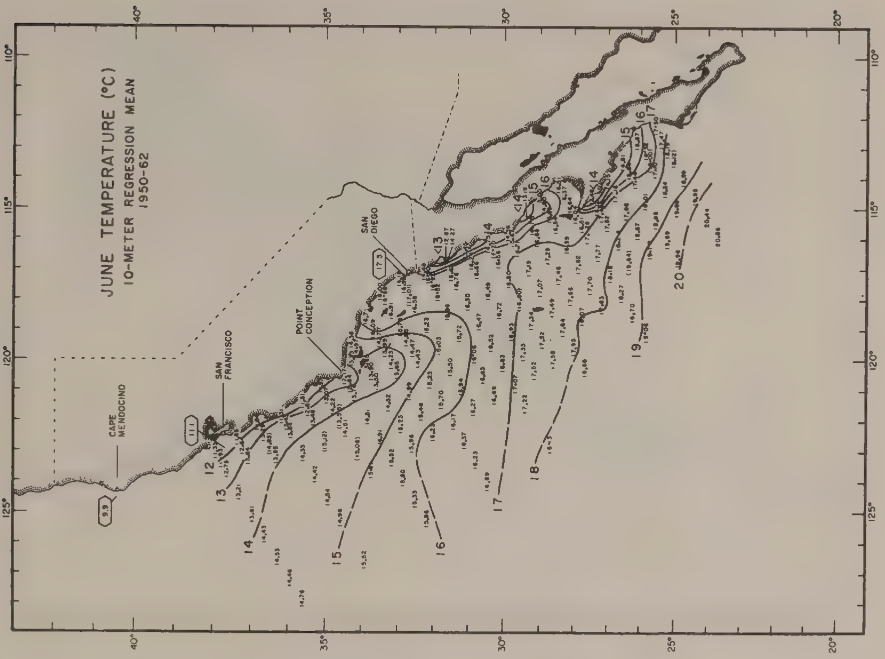
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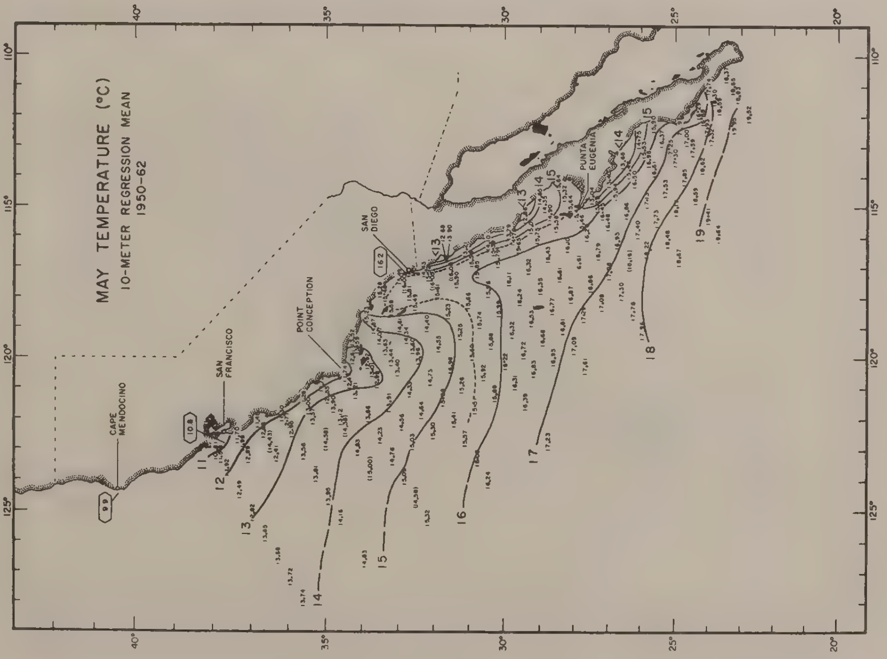
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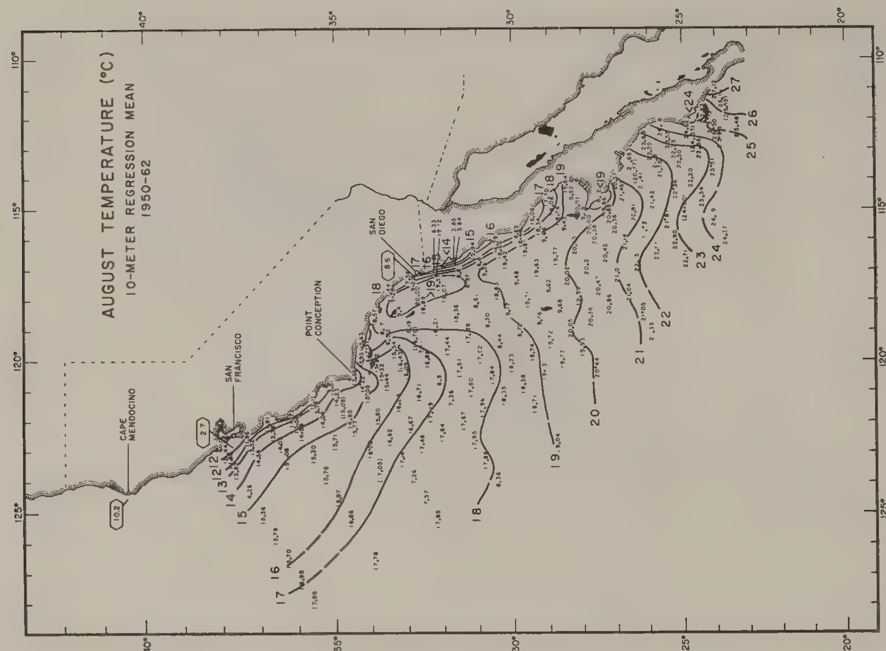
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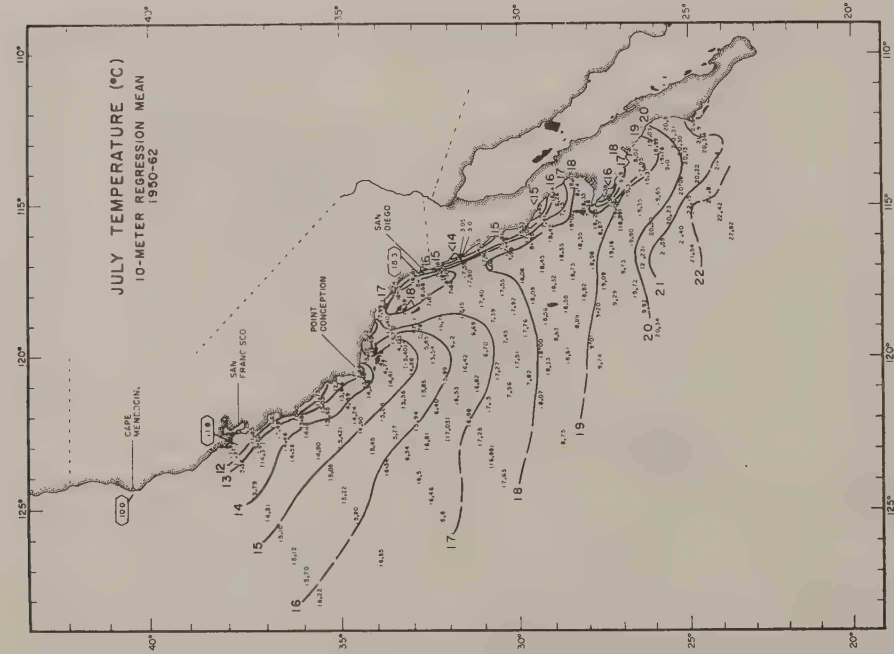
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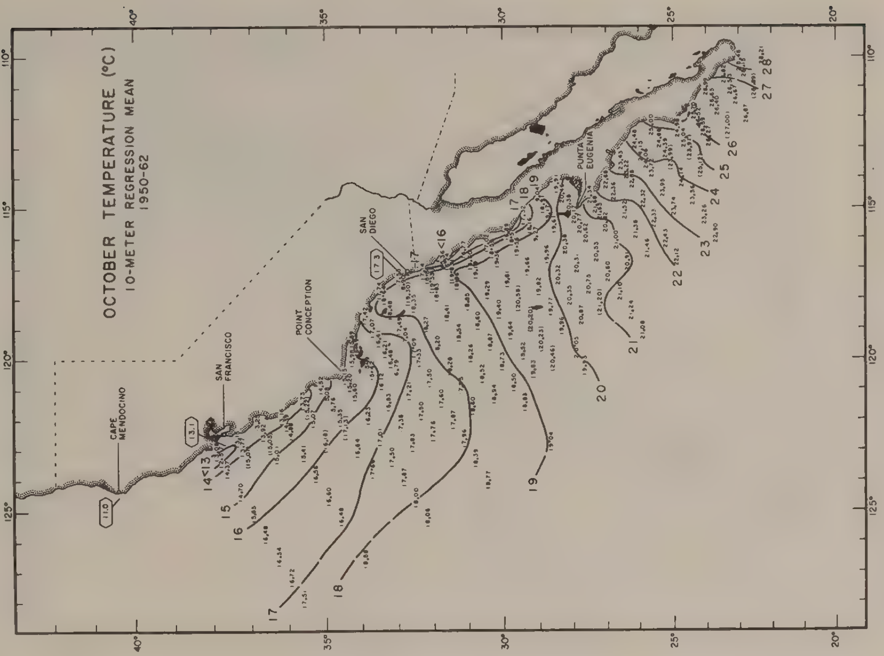
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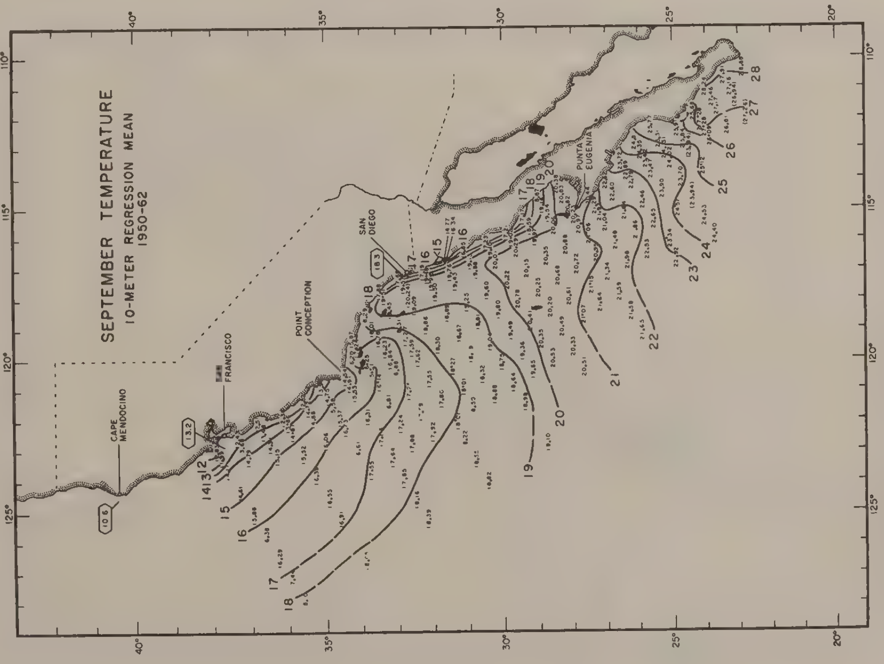
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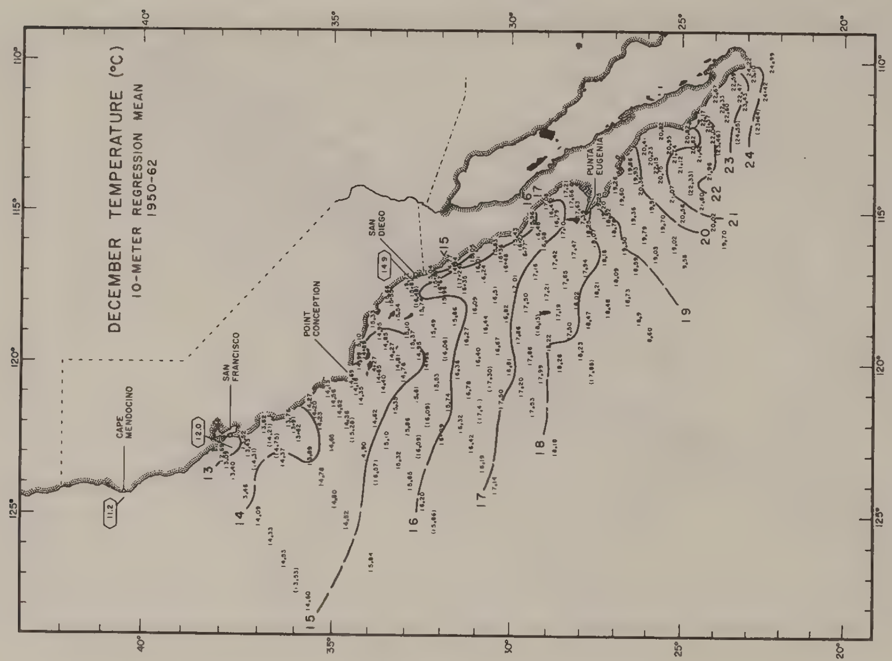
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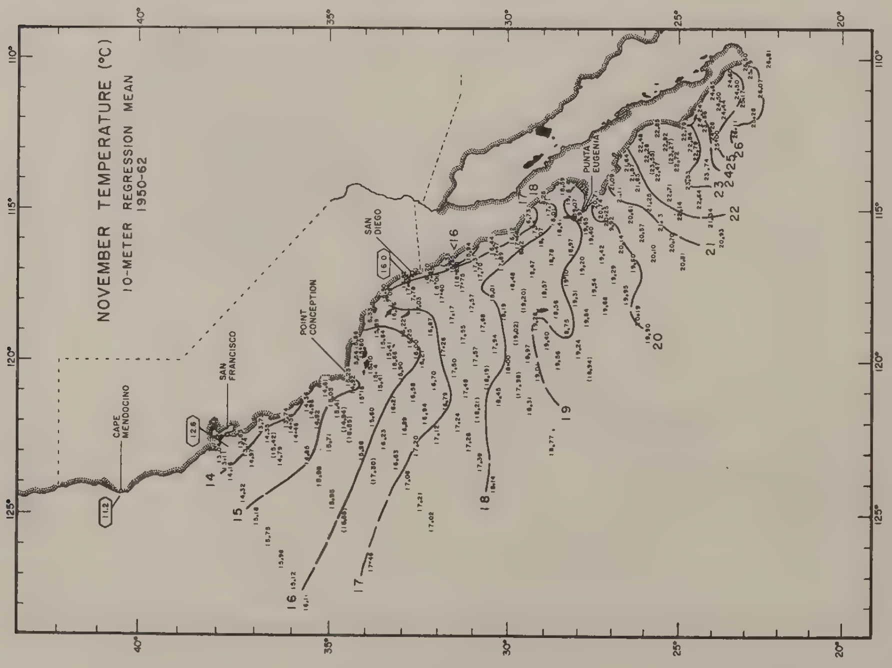
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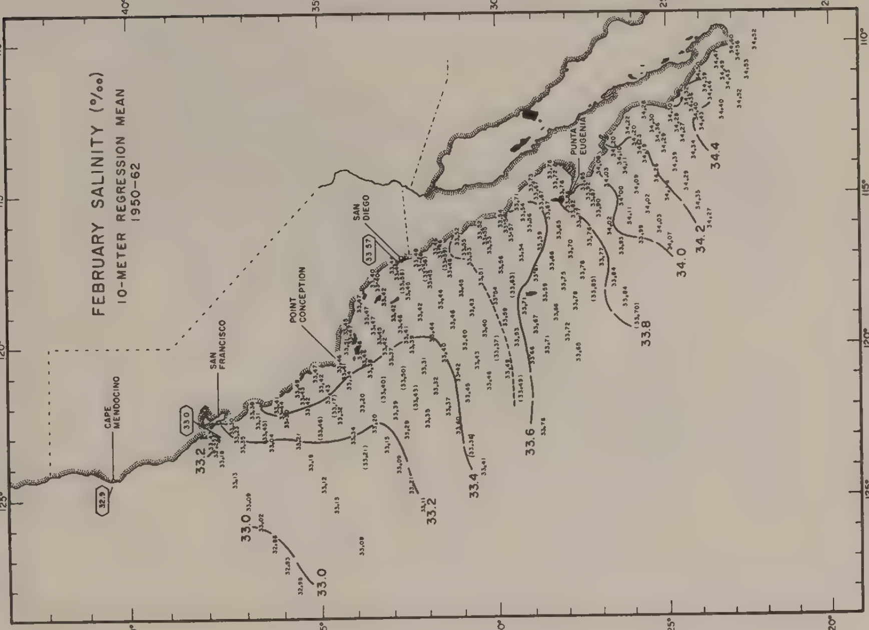
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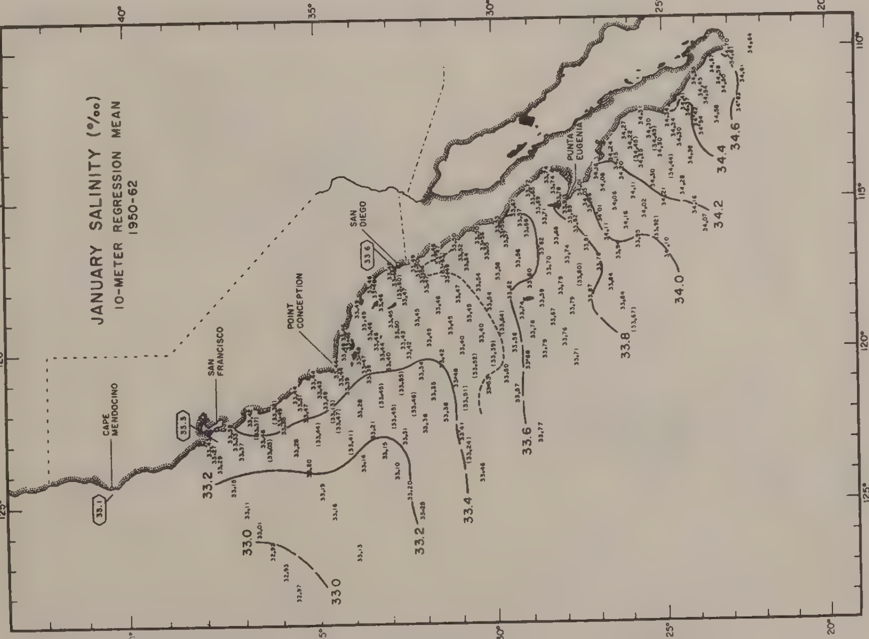
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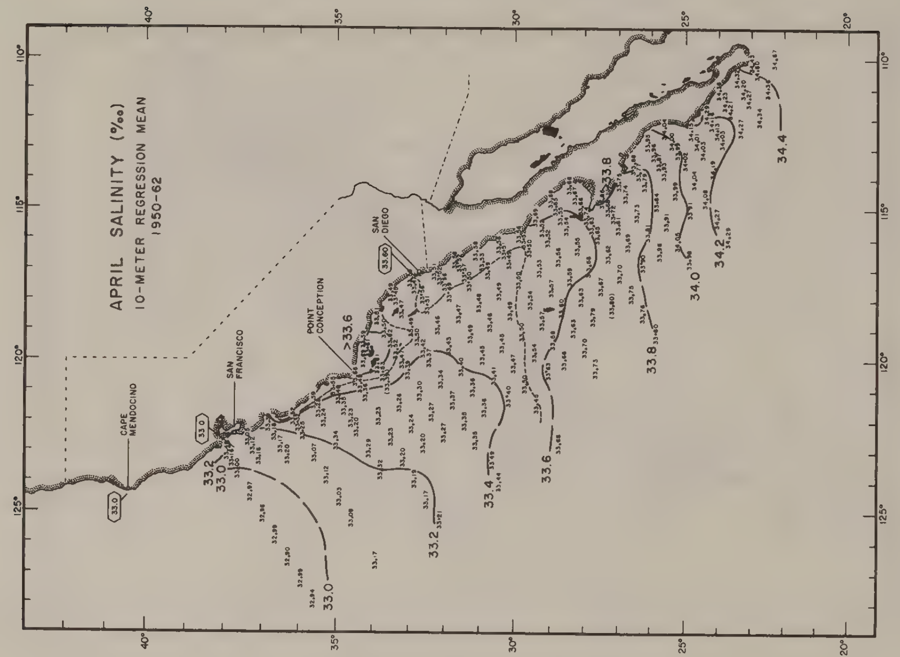
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33.0
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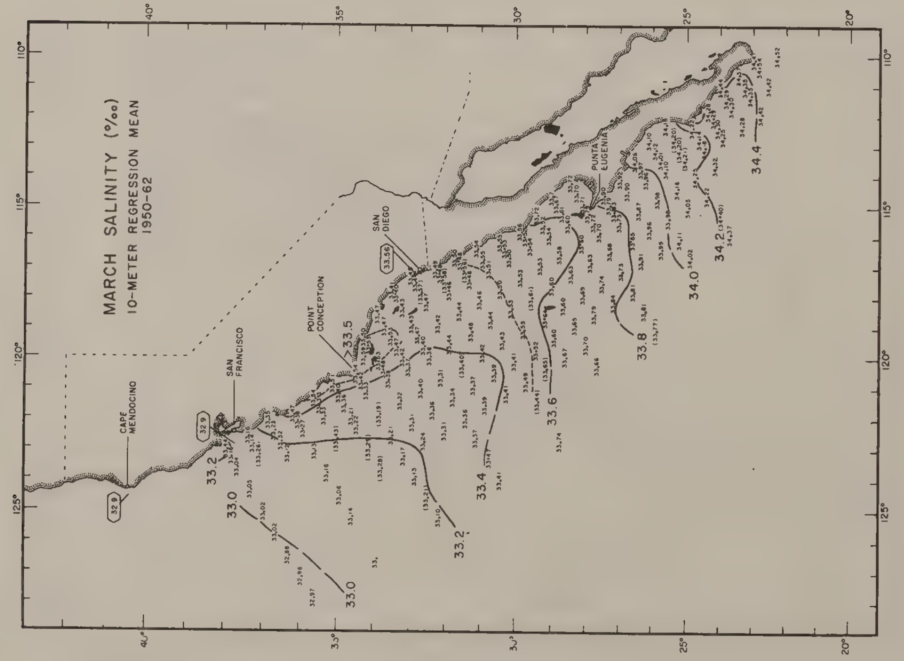
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1950-62
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
32.9
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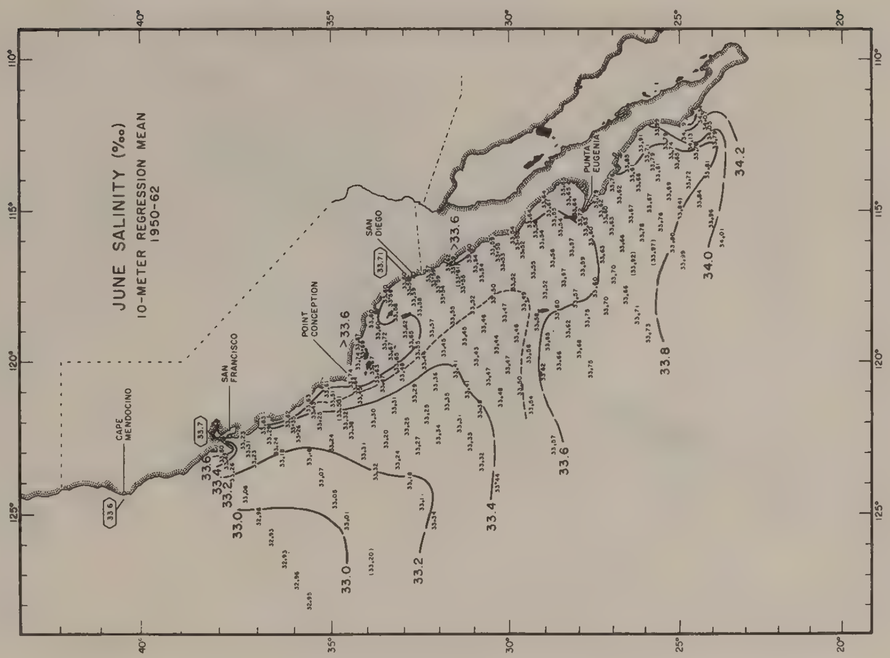
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1950-62
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
33.6
33.7
33.71
>33.6
33.0
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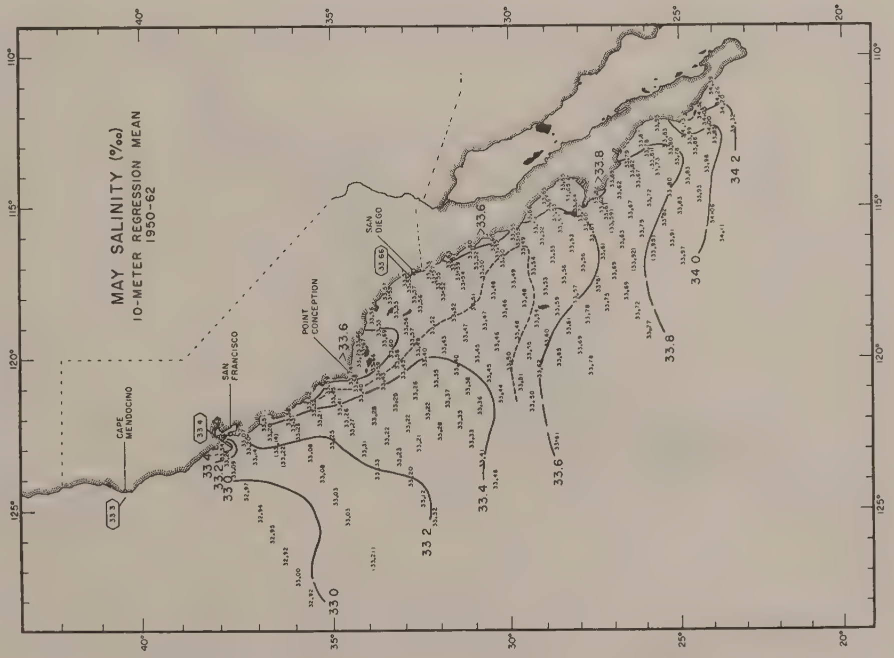
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1950-62
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
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>33.6
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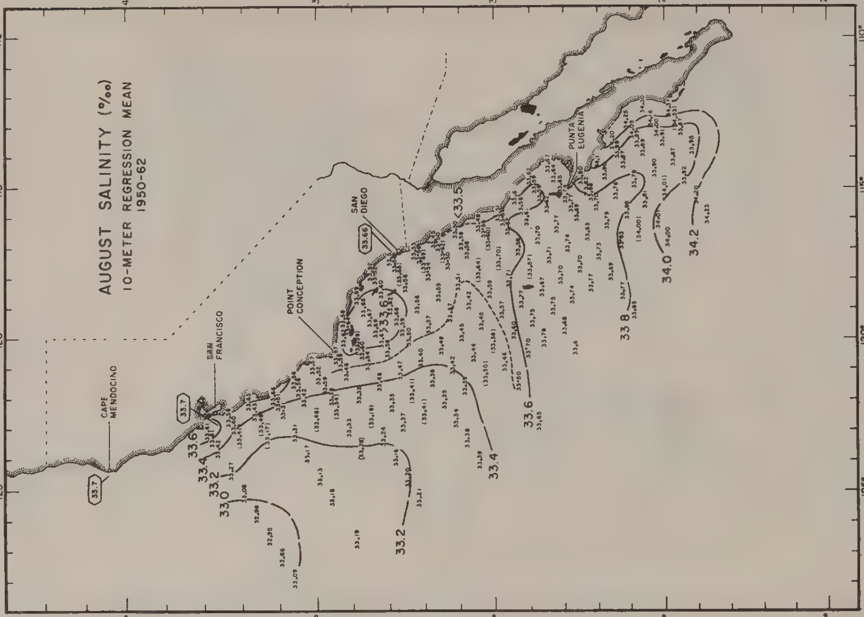
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1950-62
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
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PUNTA EUGENIA
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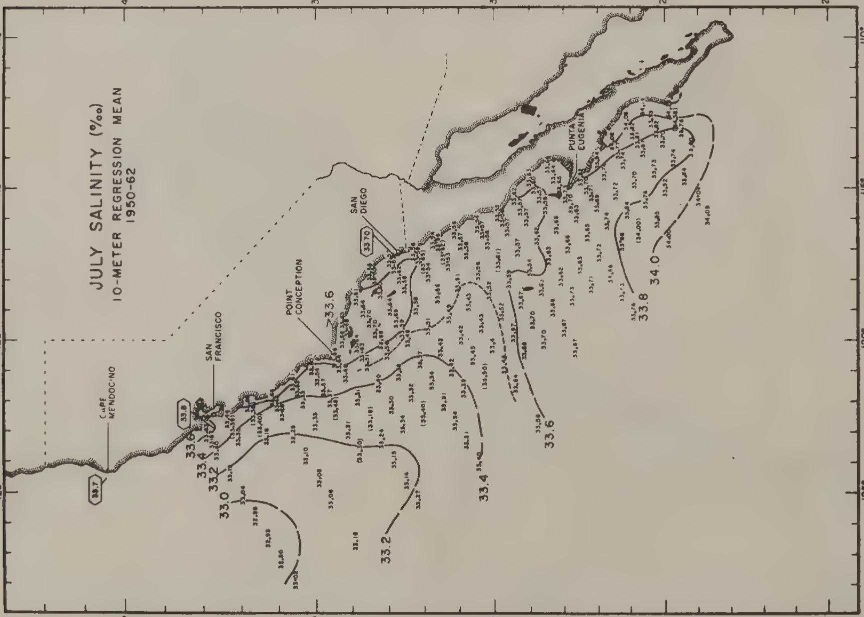
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CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
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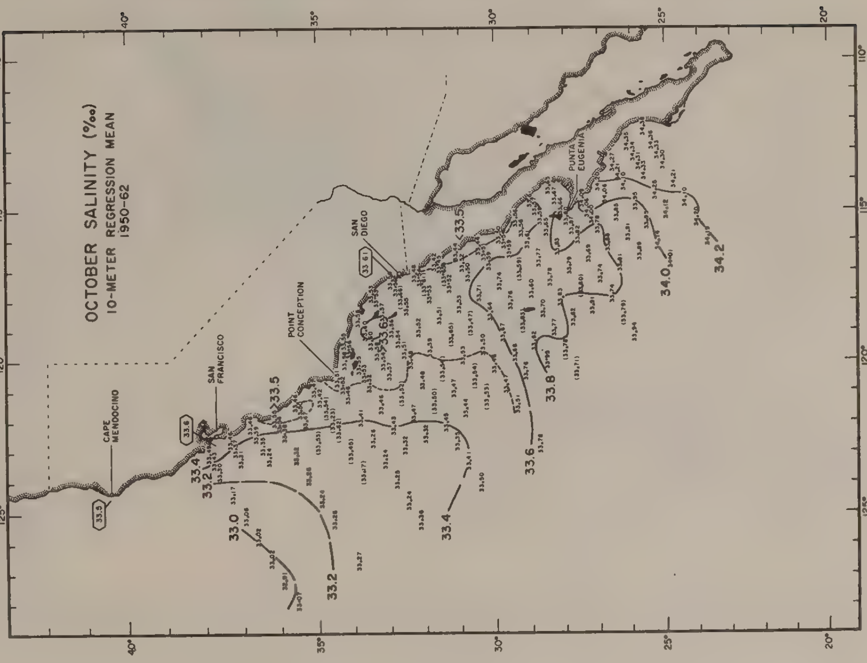
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CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
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PUNTA EUGENIA
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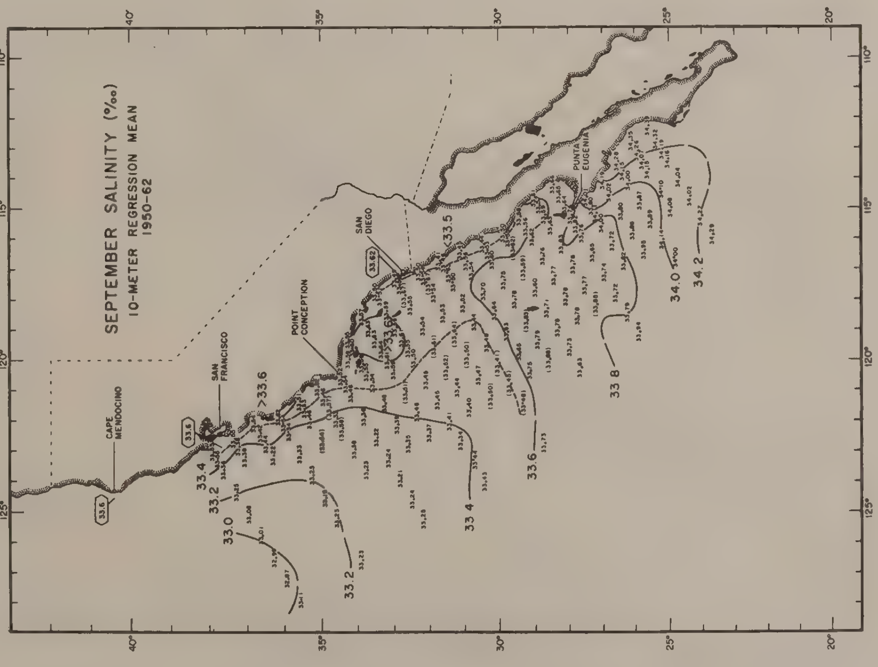
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1950-62
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
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PUNTA EUGENIA
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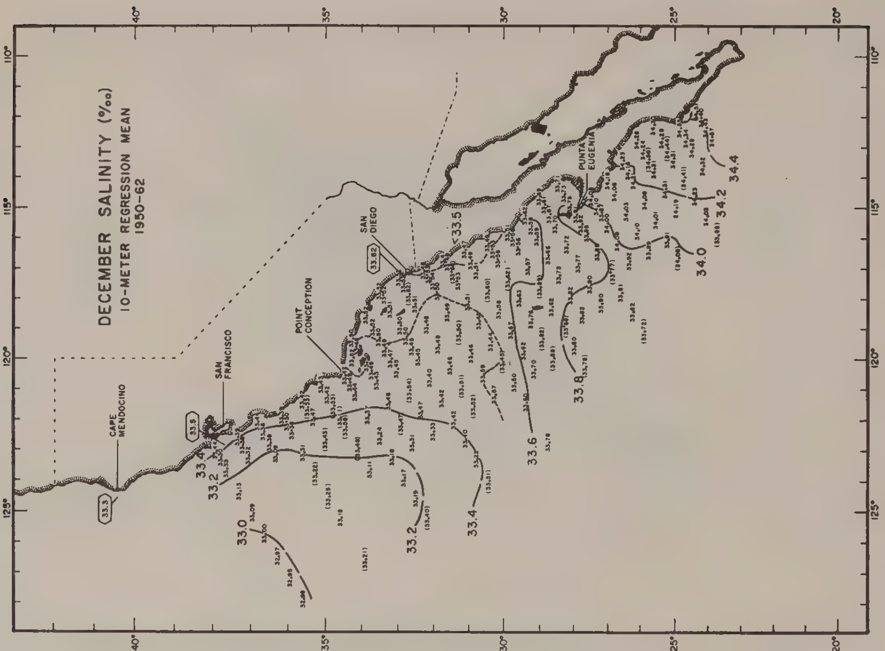
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1950-62
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
33.3
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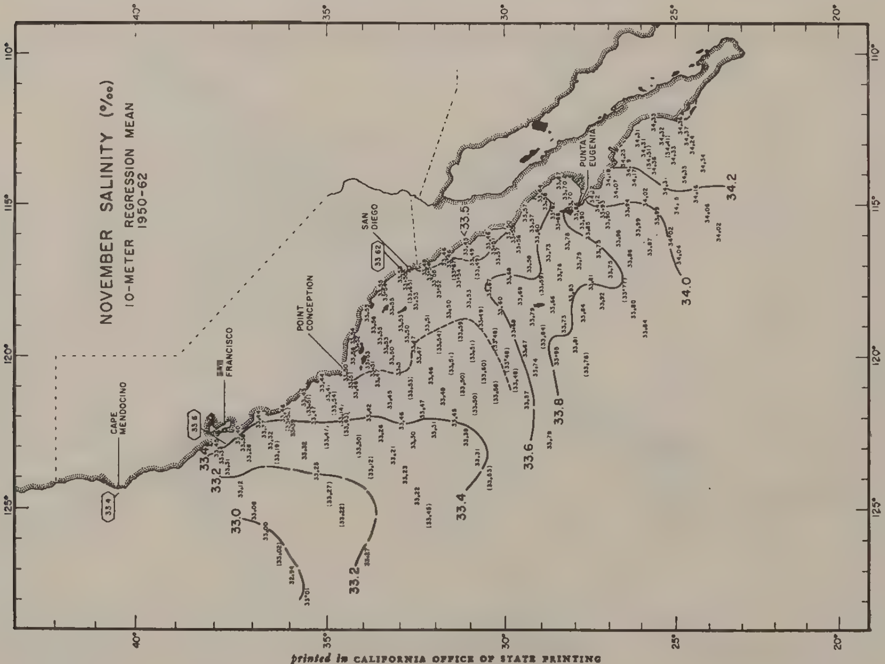
NOVEMBER SALINITY (‰)
10-METER REGRESSION MEAN
1950-62
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
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